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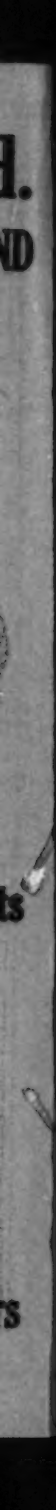

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

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Issue of Journal. The Journal appears in six issues per volume, viz., February, April, June, August, October, and December. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed periodically by revisions of the Library Catalogue and List of Members. The List of Members brought up to March, 1922, is now issued.

Members of all classes are entitled to receive these publications free; for additional copies of the Journal they will be charged at the price of seven shillings and sixpence per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel Post Department, as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel post packets will not be re-addressed, but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms and localisms should be indicated by means of inverted commas.

Foreign weights, measures and costs should be given whenever possible, and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of December, March, June or September, as the case may be. Subsequent delivery may be too late for insertion.

The Council desire to draw the attention of authors to the serious increase in the cost of production. Papers, both for the Journal and for communication to the Institution, should be as concise and condensed as possible.

Communications. The Council invite members to submit papers for the forthcoming session. Communications to the Institution will, subject to the approval of the Publication Committee, be published in the Journal.

Cases for Binding. Cases for binding the Journal can now be obtained from Messrs. Wm. Speaight & Sons, Ltd., 98, Fetter Lane, London, E.C. 4, at a cost of 1s. 6d. post free. Remittance to accompany order.

Members who desire to have their Journals bound in these cases should send their Journals to Messrs. Speaight & Sons, Ltd., with an additional remittance of 3s. per volume.

This notice applies also to all previous volumes.

Reprints of Papers. Contributors of papers to the Journal are entitled to 25 free reprints of their papers, and, if desired, a further 25 copies may be had at the following rates. Orders for reprints should be sent to the printers when M.S. is forwarded to the Editor.

2 pp. ..	2s. 0d.	12 pp. ..	7s. 6d.
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8 pp. ..	5s. 0d.	20 pp. ..	12s. 6d.

Medal for Student Member. A medal and a prize of 5 guineas will be awarded annually by the Council to that Student Member of the Institution of Petroleum Technologists who shall in their opinion have presented a paper of outstanding merit during the year.

Appointments Register. A Register will be kept at the offices of the Institution for the convenience of firms requiring the services of members and for members requiring appointments, but on the distinct understanding that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library at No. 5 John Street, Adelphi, may be consulted between 11 and 4 daily. Extensive additions are being made to the current and standard literature on Petroleum.

Additions since publication of last Journal :—

From the Chemical Catalogue Company :—

The Recovery of Volatile Solvents. By Clark S. Robinson.

From the Director of the Geological Survey and Museum :—

Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for 1921.

From the Consulado General de Guatemala en Londres :—

Petroleum Law of Guatemala.

From the Colorado School of Mines :—

Quarterly of the Colorado School of Mines, Vol. 17, No. 4, Supplements A and B, October, 1922.

From the Government of the Commonwealth of Australia :—

Papua, Annual Report, 1921–1922.

From the American Society for Testing Materials :—

Proceedings, Vol. 22 ; Part 1, Tentative Standards ; Part 2, Technical Papers.

From the Department of Mines, Canadian Geological Survey :—

Geology and Mineral Deposits of the Bridge River Map-Area, British Columbia. By W. S. McCann.

Summary Report, 1921, Part B ; Part E, Iron-Bearing Rocks of Belcher Islands, Hudson Bay. By G. A. Young.

Relationship of the Pre-Cambrian (Beltian) Terrain to the Lower Cambrian Strata of S.E. British Columbia. By S. J. Schofield.

From the Department of the Interior, United States Geological Survey :—

Felspar in 1921. By F. J. Katz.

Silver, Copper, Lead, and Zinc in the Central States in 1921. By J. P. Dunlop and F. Begeman.

Antimony in 1921. By Frank C. Schrader.

Arsenic, Bismuth, Selenium, and Tellurium in 1921. By Victor C. Heikes.

Platinum and Allied Metals in 1921. By James M. Hill.

Clay in 1921. By Jefferson Middleton.

Salt, Bromine, and Calcium Chloride in 1921. By K. W. Cotterill.

Barytes and Barium Products in 1921. By George W. Stose.

Asbestos in 1921. By Edward Sampson.

Gems and Precious Stones in 1921. By B. M. Stoddard.

Professional Paper No. 131–A. Additions to the Flora of the Wilcox Group. By E. W. Berry.

Bulletin No. 707. Guidebook of the Western United States. Part E : the Denver and Rio Grande. Western Route. By Marius R. Campbell.

Bulletin No. 722. Report on Progress of Mineral Resources of Alaska. Investigations in 1920. By A. H. Brooks, and others.

Bulletin No. 724. Nitrate Deposits in the Amargosa Region, South-Eastern California. By L. F. Noble, G. R. Mansfield, and others.

Water-Supply Paper No. 463. Surface Water Supply of U.S., 1917, Part xii. North Pacific Drainage Basins. B : Snake River Basin.

Water-Supply Paper No. 478. Surface Water Supply of U.S., 1918, Part viii. Western Gulf of Mexico Basins.

The Sedimentary Deposition of Oil and the Relationship of Fossil Wood to Oil. By Murray Stuart.

The Council would be very grateful to members, who are authors of books on petroleum and allied subjects, if they would kindly present a copy of their works to the Library of the Institution, and for review in the Journal.

The attention of members is drawn to the new supplement of the Journal which deals with current Petroleum literature. To make this section of the maximum usefulness it is necessary that there should be full co-operation between chemists, engineers and geologists, and that matter which has inadvertently escaped notice shall be immediately sent to the Editor. The Institution is indebted to Mr. W. J. Wilson for the compilation of the bibliography.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to Messrs. Commercial Publicity Service, 58, Warwick Street, Regent Street, London, W.1.

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

ENG. LIEUT. H. D. ADAM, R.N. (Special Reserve), has been appointed to H.M.S. "Dolphin," at Portsmouth, for a fourteen-day course, commencing on February 3rd.

MR. F. E. CHERRY has taken up the management of the property of the Colombian Oilfields, Ltd., in Colombia.

MR. H. J. DAVIES has returned to Burma.

MR. T. R. H. GARRETT is returning home from Burma.

MAJOR J. A. LAUTIER, who has, during the past few days, relinquished his position of Delegate of the French Petroleum Department in London, has now been attached to the same Department in Paris (85, Boulevard du Montparnasse, Paris), where Members of this Institution who apply to him will always be heartily welcome.

MR. T. G. MADGWICK has proceeded to South America, and will be absent for several months.

MAJOR H. W. MERIVALE is returning to England from Barbados.

MR. W. E. AYLWIN has joined the staff of the Anglo-Persian Oil Company at Abadan, Persian Gulf.

MR. GEOFFREY BARROW has gone to Venezuela.

Mr. R. L. C. BLEECK has been stationed by the Anglo-Persian Oil Company at Salonika, Greece.

Mr. A. W. Nash has left Messrs. Bewick, Moreing and Company's staff after nine years' service, and has been appointed Senior Lecturer in Petroleum Technology under Professor Thompson at Birmingham University.

Mr. E. R. Redgrove, late Chief Chemist of the Vacuum Oil Company, has joined the Board of Snowdon and Co., Ltd.

Mr. R. G. Neilson, Refinery Manager for the Anglo-Persian Oil Co., Ltd., at Abadan, Persian Gulf, 1913–1920, and now on the London Staff, has received the C.B.E. for services rendered during the war. The investiture took place at Buckingham Palace on February 22nd, 1923.

OBITUARY NOTICE.

P. C. A. STEWART.

It is with great regret that we have to record the death of Mr. Philip Charteris Anstruther Stewart, who was drowned in Trinidad, B.W.I., on January 14th, 1923.

Mr. Stewart, who was a son of the late Colonel Charles Edward Stewart, was acknowledged as a distinguished petroleum geologist. After completing his training at the Royal School of Mines, he went to Mexico in 1900, where he remained for about two years. He then joined Mr. D'Arcy's first expedition to South-West Persia in 1902 to 1904, and afterwards obtained an appointment on the Egyptian Government Geological Survey. He subsequently became connected with Messrs. S. Pearson and Sons, Limited, on their Mexican staff, and afterwards as resident geologist in London, a position which he occupied at the time of his death.

Mr. Stewart was an Associate of the Royal School of Mines, a Fellow of the Geological Society, an Associate Member of the Institution of Mining and Metallurgy, and a member of the American

* * * *

Association of Petroleum Geologists, and several other scientific societies. His untimely death, at the age of forty-eight years, will be deeply regretted by all connected with the profession, and he will be greatly missed by his many friends and associates. He is survived by his mother, to whom we extend our deepest sympathy in her irretrievable loss.

NOTICE.

It is proposed on two evenings next session to hold meetings devoted to the reading and discussion of short papers on "Fishing Operations" and "Shutting off water" respectively.

Members of the Institution who are interested in these topics should send in their contributions before September 30th, 1923.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

A MEETING of the Institution of Petroleum Technologists was held in the Rooms of the Royal Society of Arts, John Street, Adelphi, on Tuesday evening, December 12th, 1922, Professor J. S. S. Brame, President, in the Chair.

The Members of Council present were Sir Frederick W. Black, Dr. A. E. Dunstan, Dr. W. R. Ormandy, Mr. H. Barringer, Mr. E. H. Cunningham Craig, Mr. Arthur W. Eastlake, and Mr. T. C. Palmer.

The President said that before calling upon the Secretary to read the list of the names of the gentlemen who had recently been elected Members, Associate Members, Students, and Associates of the Institution, he desired to refer to the great pleasure it gave the Council, and the honour it did the Institution for him to have to announce that four of the gentlemen elected as Members were prominently connected with the petroleum industry of France. He felt it was particularly gratifying that French oil experts should come into the fold of the British Institution of Petroleum Technologists.

THE SECRETARY read the following list of the names of gentlemen recently elected :—

Members.—Frederic Bordas, George Gane, Henry Gault, William Henry Goodchild, Albert Guiselin, Henry King Hiller, Francis Conway Jenkins, Willem Carel de Leeuw, Reginald Marshall, and George Eustace Stott.

Transference from Associate Member.—Ernest Cecil Craven and William Rupert Weatherhead.

Associate Members.—Charles Edwin Burnett, William George Coutts, Louis Victor Alfred Fowle, and William Wilfred Neville.

Transference from Student.—William Graham, Andrew Menzies, and Alan Faulkner Strickland.

Students.—Francis John Brakenridge, Archibald Brill, Clifford Officer Graham, and Albert Leslie Wilson.

Associates.—Orange Reed Baxter and Frederick Robert de Harden Jones.

The President said it was hardly necessary for him to introduce Mr. Madgwick, who was to read the paper on the present occasion.

Due to the very great difficulties experienced by the Publication Committee in arranging the papers for the Session, Mr. Madgwick had been asked to read his paper at an earlier date than had been anticipated, and it was well the members should know that fact.

The following paper was then read :—

Some Aspects of the Occurrence of Oil in Russia.

By T. G. Madgwick, M.Inst.M.M. (*Member*).

With the renewal of interest in the possibilities of Russia as an oil producer, which the course of recent events has tended to create, it is felt that a paper dealing with this side of the Russian Oil Industry will be of service, both because anything of a general survey of the Russian Oilfields is difficult to arrive at, and because it must be a question which many are asking, in these days of stock-taking of the world's oil resources, as to whether Russia is destined to play a *rôle* in the future comparable to what she has in the past. To discuss the subject within the limits of a paper doubtless to some would seem futile, but granting the obvious fact that a detailed study of all the oil occurrences in the old Russian Empire is here impossible, it must be conceded that a reasoned estimation of the possibilities of Russian oil by the members of this Institution ought to fulfil a very useful purpose—anything of a quantitative nature being out of the question.

At the outset it is well to define what is comprised under the term Russian Oilfields. For the purpose of this paper it is proposed to consider only such portion of the Russian Empire lying between the meridians 35° and 75° E. of Greenwich, since the few recorded occurrences in Eastern Siberia are but imperfectly known and Sakhalin may be regarded as too remote to play any part in conjunction with the main fields. The map shows the distribution of oil occurrences within this area.

For several years before the war the Russian oil industry was in a state of flux, partly due to exhaustion of the older pools, and partly to the change in technical operations, of which the most striking has been the adoption of the rotary method of drilling, in this way American methods having come to help Russia just as the experience gained in Russia had formerly been of service in California when heavy ground was first there encountered. Two other factors must also not be forgotten, the relatively late development of communications in Russia which barred many districts from the attention they might have otherwise received, although until the Baku productions began to drop there was little inducement to their development, and also the frequent political upheavals that

have been such a handicap to the industry. Under these circumstances it is no surprise that the Russian oil industry has failed to keep pace with that of other parts of the world, and therefore presents far less of interest than the question of the oil occurrence pure and simple.

A great quantity of geological and other literature is in existence, regarding the occurrence of oil in Russia, not always accessible to the general reader, but comparatively few efforts have been made to treat of it as a whole. The following attempt to group the more important scattered localities is offered rather as a nucleus for discussion than as suggesting limits to the areas of value for oil prospecting. The limits lie rather in the imperfection of our knowledge of so vast a country as that with which we are dealing.

The very widespread occurrence of oil in Russia is, perhaps, not realised by the general public for whom Baku has always stood as a synonym for Russian oil, so that a general discussion of the subject will have a field of interest wider than a purely technical one. In any attempt to study oil occurrences over a wide area the stratigraphical side becomes the most important since the usually quite minor tectonical details which are without doubt equally important factors in the accumulation of the oil into commercially exploitable pools almost disappear under the scale with which we are perforce obliged to regard them. Without the stratigraphy being such as can supply the oil the structure cannot give us the reservoir to contain it. We shall deal with the geology as briefly as possible.

Regarded on small enough scale the geology of this part of Russia is fairly simple. We have the great Russian plain over which vast areas of Permian and Mesozoics lie almost horizontally upon older Palæzoics, but little more disturbed, and are in turn concealed beneath Tertiaries and recent deposits, notably towards the south. Nearly meridionally in the more northern portion we have the ancient range of the Ural mountains, in which the Palæozoics are upturned and much metamorphosed, but have been eroded to inconsiderable elevation, and in the south we have in European Russia the Caucasus with its north-western extension into the Crimea, and its Asiatic links with the Tian Shan and Pamirs. The main ridge of the Caucasus is a portion of the massif lying further south, from which it is separated by the important trough fault of Transcaucasia, through which the Transcaucasian Railway now runs and which in Sarmatian times appears to have united the Black and Caspian Seas. The main ridge has been elevated in later geological times to two of the highest points in Europe, *viz.*, Mount Elbruz, 18,560 ft. high, and Kazbek, 16,531 ft. high. It therefore differs markedly from the Ural, not only as regards elevation, but in the formations which enter into its

composition. Thus the Palæozoics and crystalline rocks only extend along the central part and more western end, whilst the important mountains of Daghestan and the east are mainly Jurassic and Cretaceous in age, as are also those of the Crimea.

On following the Caucasus main ridge, both east and west, we find the Cretaceous disappears beneath a girdle of Tertiary and later rocks, the former entering into the structures with which we are mainly concerned, *i.e.*, the oilfields. It should be noted, however, that the Cretaceous appears again over a vast area drained by the Don and Donetz, and along the Volga and skirting the northern shore of the Caspian it is again developed along the flanks of the foothills of Turkestan. This must not be forgotten in assessing the concealed oil possibilities of the northern Caucasus.

East of the Ural the Devonian rocks extend away into Asia, but westwards they dip beneath the Carboniferous and younger formations. Further west we have structures roughly parallel with the main ridge of the Ural, which are of especial interest from their association with oil. In the north older rocks appear in the Timan Hills, to the west of the lower waters of the Petchora and its important left bank tributary, the Izhma, and at the southern end of these hills is an occurrence of oil known as the Ukhta field, which has quite recently come rather into prominence, owing to efforts to develop its oil resources during the period when Baku was cut off from northern Russia in 1918–1919. The oil occurs in Devonian rocks, which also have important deposits of oil shales.

Parallel to the Southern Ural along the right bank of the Volga we have more oilshales in the Zheguli hills of the Samara and Southern Kazan Governments, only these are Carboniferous. They form an anticline but to the east of the river, where actual seepages occur, the whole area is covered by Permian rocks, which are petroliferous in the Government of Kazan, Samara, Simbirsk, Ufa and Orenburg, so that it is an open question where the oil comes from. The connection with Permian sands at once draws our attention to the similar occurrences at the northern end of the Caspian in the so-called Emba field, and it is worthy of note at the same time that oil has been reported from these beds along the Moscow-Archangel Railway, not far from Vologda and along the river Sukhona, over a wide area, and Pallas found a seepage at the junction of the Trias and Permian at Semenova on the Suktanka, N.N.E. of Nizhni, associated with sulphur and gypsum. The line thus indicated is suggestive.

The mapping of the geology of these regions would be easy were they not often concealed beneath recent formations which may largely be attributed to deposits of the Caspian, at no very distant date covering the whole of the region south of the Ural. and having

connection with the Arctic. The relics of this sea are well illustrated in the innumerable lakes which stretch across the map, and of which the Black and Caspian Seas are the principal ones. The thickness of the recent deposits in the valleys bordering this plain in the east, such as those of the Amu Darya (Oxus) and the Syr Darya (Jaxartes), is considerable, and it is only along the margins of the valleys that the underlying older Tertiary and Cretaceous rocks are exposed, where they rest against the flanks of the older rocks.

To turn to more detail we will first consider the Caucasus. It is usual to describe the Northern Caucasus under the divisions made in respect to the two big Cossack territories, *viz.*, those of the Kuban and those of the Terek. Since these derive their names from the principal rivers of the northern flank, and have therefore a geographical signification, and moreover the two regions are distinct from an oil point of view, there is something to be said for retaining this. With regard to the eastern division, the Terek, no separation can be made from Daghestan to the south, in which country the main difference is that the Caspian Sea borders the hills and the Steppe lands which appeal to the Cossacks are consequently absent. The mountains end off rather suddenly at the S.E., and are succeeded by a broken tract with isolated hills jutting out into the Caspian Sea, this being known as the Apsheron Peninsula, upon the southern side of which the city of Baku is situated. This peninsula is clearly carried across the Caspian as a submarine ridge dividing that sea into two basins, and reappears on dry land as the Balkhan Hills, near Krasnovodsk, and is carried on as the mountains north of Meshkhed and Herat.

Southwards from Baku the low land widens out and embraces the mouth of the Kura, this being continued then to the N.E. as the trough fault before mentioned, which already south of Elizavetpol is bordered by high mountains in which granite and metamorphics, together with Jurassics, Cretaceous and eruptive rocks appear. Ascending the valley of the Kura the rise is gradual, until its main left bank tributaries, the Alazan and Yora are reached, after which more marked relief ensues, reaching up to the pass towards the Black Sea, near Mikhailovo, over three-quarters of the way from the Caspian, where is a rapid descent of some 2,000 feet. The Black Sea plays a similar *rôle* in regard to the southern shore of the north-west Caucasus to that which the Caspian does to the coast of Daghestan and then in the north-west we have a very similar termination to the main range as at Baku, in the shape of the Taman Peninsula, separated from the corresponding Kertch Peninsula of the Crimea by the Straits of Kertch.

Probably no oil centre was better known to antiquity than

that located near Baku, where both the oil and gas have been worked from time immemorial, the situation of the city on one of the important trade routes between Europe and Asia tending to facilitate this. With the introduction of the drill as a means of development no great success appears to have crowned the earlier efforts in the Kuban territory, and it was not long before the new method was tried at Baku, more, however, with the result of terrifying the natives at the first gusher than with its immediate and rapid adoption, as in America. Upon the abolition of the oil monopoly in 1871 developments became rapid, and with but scanty markets in the vicinity the natural outlet was up the Volga to the interior of Russia for which the richness of the productive horizons, as well as its favourable geographical position, eminently favoured its growth. Just as Pennsylvania had been the great pioneer of development from Palæozoic rocks, so Baku stands as the typical field for oil from the Tertiaries, and as in America oil was subsequently developed over a wide area, and from both Tertiary and Cretaceous rocks, so we now know of equally widespread oil occurrence in Russia in both Cretaceous and Palæozoic rocks, although, so far, the Cretaceous has been the only division to give much production. We may even draw a certain analogy between the occurrence of the Tertiary oil in California and in the Caucasus on the one hand, and the occurrence of the older oil beneath the plains of the Mid-Continent, and in the hills of the Appalachian field of America, and that under the great Russian plain along the western side of the Ural on the other. Whether we may take this resemblance as a portent of future production in Central Russia we are not yet in a position to say.

General Remarks on the Caucasus.

It may be that no second Baku will ever be found in Russia. The conditions were exceptionally favourable for the accumulation of oil in the main fields of Balakhani-Sabunchi-Romani-Surakhani to the north of Baku, and the smaller area of Bibi-Eibat to the south. It is noteworthy that the vast amount of wild-cat drilling done by the various interests in surrounding districts, as well as in those more remote, has never resulted in the discovery of anything to compare with these two famous pools, although many of lesser importance have been proved, and undoubtedly many yet await development. We must not forget that in the past Baku set the standard for oil production, both as regards yield and price. The price has only of late years been relieved of the continual depression brought about by the magnitude of the yield. Moreover, the admittedly grandfatherly legislation and attitude of the old Government were such as to handicap the rational development of

the industry. The temptation to build up and then conserve a large manufacturing industry on the Volga was primarily justifiable, but a wider and more useful market for the very valuable products of Baku oil would seem necessary in the future if full justice is to be done to the oil yet remaining.

In view, therefore, of this admitted pre-eminence of Baku we will commence our review of the oil occurrence with those pools associated with the Tertiary rocks lying as a wide girdle around the main ridge of the Caucasus, and which may be considered as standing in relation to the Carpathian fields in one direction and those across the Caspian Sea towards the east, with both of which areas they obviously stand in close connection. Now, Caucasian oil is most probably of Tertiary origin, the occurrence of oil or gas in the Cretaceous, Jurassic and even Triassic rocks being of an altogether subordinate character, and not likely to have materially added to the oil accumulated in the pools hitherto worked. The probable source of Caucasian oil is the thick shales of the lower Miocene and underlying Tertiary formations although we must avoid assuming that away from the more folded Cretaceous areas in the Caucasus there are not also abundant accumulations of oil at depths which at present are conjectural.

With the thinning of the overlying Tertiaries such Cretaceous pools may become accessible as in the case of the fields lying at the north end of the Caspian, where oil is found in Lower Cretaceous rocks, whether *in situ* or derived from deeper formations is at present difficult to say. Further east we shall see that the Fergana stage of Lower Eocene age, or perhaps in part Upper Cretaceous, is associated with oil, again, quite reasonably, of indigenous nature, without excluding altogether the possibility of a deeper source. It is true similar doubts might arise as to the possibility of a deeper seated source for the Caucasian oil, but as far as the Apsheron peninsula is concerned, no evidence of a deeper occurrence than, say, the Amphisyle Beds, has been observed, and the association of other Caucasian pools with rocks of Miocene age suggests a like relatively short migration.

A glance at the map of the Caucasus shows the concentration of oil indications at the two ends of the range in the peninsulas of Taman at the north-west and Apsheron at the south-east, the phenomena of the former being repeated across the Straits of Kertch westwards, in the Crimea, and of the latter across the Caspian in Transcaspia. The structure of the Taman and Apsheron peninsulas is markedly similar from a topographical as well as a geological point of view, consisting of undulating plains, with low hills in which two folding systems have combined to form rather

complex structures, and each has long been famous for its oil indications, and its mud volcanoes. Yet the one more remote from Europe has produced huge quantities of oil, that nearer has hardly justified its admission to the category of proved oil territory. This is not from lack of efforts to develop it, but owing to the fact that the favourable formation for the accumulation of oil, such as occurs on the Apsheron is absent in the Taman, at any rate, so far as concerns the Miocene. The deeper horizons still retain possibilities.

Of the two sides of the Caucasus the northern presents simpler structures, and has already proved its possibilities at the isolated pools of Kudako, Ilsky, Maikop and those near Grozny. The formation found in all these resembles more the Taman type than the Apsheron, *i.e.*, a relative scarcity of sands which, however, are more abundant in the Terek (Grozny) field than further west in the Kuban areas. The Caspian littoral itself has been disappointing hitherto, in spite of the temporary success achieved twenty years ago at Berekei, and it is a not unfair statement to say that the true Baku facies is local, having been developed only so far on the peninsula and its immediate vicinity. Owing to this variation it is difficult to correlate the Neogene formations in different parts of the Caucasus, and the Russian geologists have had to modify their views of recent years with regard to the succession generally. Usually the Mediterranean stage is unchallenged, and is frequently followed by a transition to the Sarmatian, which, in turn, is usually divided into three sub-stages, the Lower with Modisla marginata and Cardium obsoletum, the middle, including the Cryptomactra beds and the Upper (not always present) with Mactra Caspia.

Above the Sarmatian, usually with a marked unconformity, follows a very characteristic formation, known as the Akchagyl, having a fauna allied to the Sarmatian, and which was formerly considered to belong to the Meotic or uppermost Miocene and is frequently found so described in the older publications. Its position, however, in the Baku district is more equivocal where it overlies the main productive formations, which, containing only fresh water fauna, have been variously regarded as of Oligocene and Miocene ages, but are now classified by Andrussov and Golubiatnikov as Pontian. This, then, makes the Akchagyl nearer Middle Pliocene in age. It is found on both sides of the Caucasus at the eastern end. When it contains oil this may be regarded as secondary and derived from below.

In the western Caucasus the Meotic is fairly well established, and over it the Pontian and the so-called "ore beds," which are of Plaisancian age.

Baku District.

Along the flanks of the main ridge the youngest rocks exposed are usually the Akchagyl or the Meotic, which are overlain by recent sands, but at Baku we find much greater development of the Pliocene in the Apsheron and Baku stages, the former again a relatively local formation extending only to Shemakha and Kuba, and the immediate vicinity, south of the Apsheron Peninsula, although it is also met with on the island of Cheleken, near Krasnovodsk.

The complete succession on the Apsheron Peninsula, after Golubiatnikov,* is, as follows (omitting the Pleistocene) :—

Baku Stage.—Limestones, sandstones, sands, clays and conglomerates with the fossils :—Cardium Baeri, C. crassum, C. catillus, Eichw., Dreissensia cf. rostriformis, Dr. Tschanda (?), etc. *Thickness* 46 *m.*

Apsheron Stage.—Limestones, boulder limestones, oolitic limestones, shell beds, sandy limestones, calcareous sandstones, sands, marls, sandy clays and clays. Limestones preponderate in the upper beds, sands in the middle and clays in the lower. The thick clay series (110 m.) has white volcanic-like sand partings in the lower portion.

The upper beds have :—Apsheronia propinqua var. oblongua Andrus. Monodacna Isseli, M. bacuana, M. lævigata, M. sublævigata, M. catilloides, Andrus., Cardium intermedium, C. eduleformis, Sjögr., Dreissensia rostriformis, Dr. cf. polymorpha. Apsheronia and Cardium intermedium are rare.

The middle beds have :—Apsheronia propinqua Andrus. and Cardium intermedium preponderate. There are also found Monodacna Sjögreni, M. nitida, Apsheronia calvescens, Andrus., Cardium raricostatum, Streptocerella Sokolovi, small Dreissensia cf. rostriformis, Neritina. In the place of Lymnæus volutinus is met L. obtusus. Fragments of petrified wood.

The lower beds have :—Mainly Cardium of the group C. diversicostatum Andrus. Lymnæus obtusus gives place to quantities of L. volutinus. Numbers of Cypris. Small Dreissensia Grimmi.

Total thickness 453 *m.*

Dark clays with partings of sand and marl. In Bibi Eibat the sands contain gas. They have :—Lymnæus volutinus, small Cardium sp., very small Dreissensia cf. rostriformis, Clessinia. Large numbers of Cypris which with Lymnæus preponderate. First appearance of Dreissensia. *Thickness* 76 *m.*

Transition.—Dark clays with partings of gas sand. In Bibi Eibat these sands contain gas. They have :—Lymnæus volutinus, small Cardium sp., Mactra (?) sp., Clessinia, Cypris and fish scales. *Thickness* 11·3 *m.*

Akchagyl Stage.—Dark shales and shaley clays, limestone and white volcanic-like sand partings. In Bibi Eibat the sands contain oil and gas. They contain :—Mactra subcaspia, M. Inostranzewi Andrus., Cardium dombra Andrus. Throughout the series are quantities of Cypris and Clessinia, Micromelania. Very many large fishes including Clupea. Algae. Bird bones. *Thickness* 49·4 *m.*

* See *Bull. Com. Géol. Russ.*, Vol. XXVII (1908).

FRESHWATER BEDS.—Clays, sandy clays, sands with clay and sands. Clays preponderate. They contain :—Quantities of Cypris, Unio (Anodonta ?), Planorbis cornu var. Mantelli Dunk., P. costatus Klein., Lymnæus socialis, Melania cf. cracilicosta Sandb., Chara Escheri Braun., Ch.. Voltzii Braun., Ch. cf. Sadleri Ung., stalks of Algæ. *Thickness* 490 *m*

UNFOSSILIFEROUS.—(*a*) Sandy-clay beds. Sands preponderate. *Thickness* 434 *m*.

(*b*) Sands and sandstones with clay partings. *Thickness* 185 *m*.

Unconformity.

LOWER MIOCENE.—Spirialis Horizon.—Silico-calcareous and sandy clay rocks with partings of ferruginous sandstones. Carry oil in places. They contain :—Quantities of Spirialis hospes Kitl., Lucina (?), Leptolepis cf. Sprattiformis Agas. Many fish scales like those of Meletta crenata.

Cedroxylon Beds.—Dark paper shales with concretions of siliceous sandy rock. They contain numerous petrified trunks of conifers of the family of Cedroxylon.

OLIGOCENE.—Amphisyle Beds.—Dark and chocolate-coloured shales weathering yellow. They contain quantities of fish remains :—Amphisyle cf. Heinrichi Heckel, Lepidopus cf. glarisianus Ag., scales of Meletta, Sparnodus, Halacantus (?).

Lamna Beds.—Green sandy shales with partings of siliceous sandy rock and white marls. Contain oil in places. Teeth of Lamna cuspidata Ag., flat Spirialis cf. Andrussowi Kitl. Jaw of a small mammal.

† See *Bull. Com. géol. Russ.*, Vol. XXVII. (1908).

Further west, outside the confines of the peninsula, we find Eocene rocks, consisting of white marls and red clays with fucoids lying upon transition rocks from the Cretaceous and overlain by dark green shales with fucoids and some sandstones and green limestones, and then unconformably by Upper Eocene limestones and shales with Meletta species.

Above these occur Lower Oligocene limestone conglomerates with Globigerina, Operculina, Textularia, Nodosoria and Lithothamnium.

These rocks are developed near the Sumgait, which drains the extremity of the Cretaceous mountains near the north-west corner of the peninsula.

To the west in the Shemakha district a true Lower Sarmatian fauna is found in friable sandstones, alternating with clays containing septaria, and then follow limestones of the Meotic stage, containing the following fauna :—Modiola volhynica Eichw. var minor, Lucina pseudonivea Andrus., Sindesmya tellinoides Sinz., Ervillia minuta Sinz., Cardium sp., Certhium Comperei d'Orb., C. bosphoranum Andrus., Mohrensternia subinflata Andrus.

These beds are overlain by Pontian in the form of oolitic and detrital limestone containing small Congeria, especially C. panticapæa Andrus. and clays and sandstones, which are 300 m. thick,

and often contain Helix and Bulimus. These seem to be the equivalent of the freshwater beds on the peninsula, and are equally overlain by the Akchagyl and the Apsheron, but no Baku stage is found so far west.

The Palæogene rocks throughout this whole district are mainly clays, yet they contain abundance of material which may have contributed to the formation of oil, and we have seen that both the Lower Miocene and the Oligocene yield seepages. They also play the important *rôle* in the phenomena of mud volcanoes, for which Baku is famous. They are, however, deficient in sands or other porous rocks, which can form good oil containers. The Baku facies of the Neogene therefore is an ideal one, for not only have we the thick masses of sands in the Continental part of the (?) Pontian, and in a modified degree in the freshwater beds, but above we have the thick Apsheron formation which effectively seals them and has done so in spite of the fact that by no means inconsiderable faulting has taken place. It is to these two factors that we must probably attribute the fact that in spite of much wild-catting over areas where surface indications of oil are comparable to those at Baku, *e.g.*, near Shemakha, so far nothing very satisfactory has been established in the way of production. It is conceivable that the original sources of oil may have been equally prolific, and they were again mainly the same Lower Miocene and underlying beds; what enabled this steadily evolving supply of oil to accumulate at Balakhani or at Bibi-Eibat was the favourable reservoir as just indicated.

As regards the structure which has contributed in a no inconsiderable manner to this accumulation, we find on the Apsheron Peninsula four directions of folding with directions N.W.–S.E., N.–S., E.–W. and N.N.E.–S.S.W. The first is that of the main ridge of the Caucasus; it dominates the N.E. part and is also that of the famous Bibi-Eibat field. The second we find at Surakhani, whilst Balakhani-Sabunchi is of the third variety. On following these folds they are found to change direction and flow into each other, this being facilitated by faulting, which is principally in the direction of the strike. The net result as far as the developed fields are concerned is that we find them on the periphery of a synclinal basin, in which lies the town of Baku. To the west of the city itself the Bibi-Eibat fold plunges north-westward, and in the later Pliocene formations no direct continuation can be traced, thus breaking connection with the southern bend of the western end of the Balakhani fold, which, beginning at Khurdalan, forms the sharp fold of the Atashka-Shoban Dagh hills, turning again towards the west at Puta.

The eastern part of the peninsula is covered with Apsheron and

Baku beds, and only the N.E.–S.W. folding is apparent, the continental beds re-appearing on Holy Island, off the eastern extremity, where production is obtained although, with the more extensive denudation of the freshwater beds the reservoir has been less favourable than in the main fields. The principal Baku field is that of Balakhani-Surakhani, the continental beds being exposed in the Kir-Maku salt marsh to the west of Balakhani, and the freshwater beds then plunging gently eastwards under the Apsheron escarpment at Romani. At Surakhani itself we have the famous Fire Temple, and the occurrence of natural gas which has been long made use of by the natives, together with the "White Oil," both of which were subsequently developed by shallow drilling in the strata overlying the freshwater beds, in all some five white oil sands being thus developed. Two grades of this high-grade oil have been found, one almost "water-white," and having a gravity of .769, and a strong smell of benzine, met with in Well No. 14 of the Baku Naphtha Co., and the more common variety of amber colour and a gravity of .776, which smells of kerosene. It is reasonable in view of the enormous quantities of gas which have escaped through these fissured rocks in past times to attribute the "white oil," not so much to filtration as to condensation from the gas. At a depth of 1,580 feet the normal oil was struck in the freshwater beds, this being of a dark green to brown colour, a gravity of ·825, and yielding 65 per cent. kerosene, and, which is of interest regarding theories of genesis, 5 per cent. of paraffin. Oil at Romani is as light as ·854, and going westwards follows a progressive increase, as we pass downwards stratigraphically, to ·927–·936 at Balakhani.

Turning now to Bibi-Eibat we find almost identical conditions. We start at about the same horizon as at Romani and again the oil increases in gravity with depth being ·860 from 1000 ft.–1300 ft.; ·872 from 1300 ft.–1650 ft. and ·880 from 2000 ft.–2150 ft. Furthermore, it has been found that wherever there is production of oil in the Continental formation as on Holy Island, at Binagadi to the west of Balakhani, Khurdalan, etc., the oil is heavy and generally around ·940. Yet we do not find the seepages issuing from the lower formations always heavy, on the contrary, that from the Amphisyle shales five and a half versts south-west of Sumgait has a gravity of ·850–·872. It therefore would seem likely that the main oil pools of Baku are derived from below, and that this gradual diminishing in gravity upwards evidences a partial filtration. This may have been more effective in the case of the Balakhani–Surakhani field than at Bibi-Eibat, where communication was probably more direct with the deep-seated sands owing to favourable combination of faulting with alternating sands and clays.

We are concerned now with an analysis of the occurrence of oil on the Apsheron rather than with any theory of migration, but it is worthy of note that these ideas receive support from the remarkable exposure of the formation which underlies Bibi-Eibat in the adjacent Yassamal valley and the Shoban-Dagh ridge, commencing only a mile and a half to the west of the pool, where the Freshwater Beds, so prolific at Bibi-Eibat, show no signs of oil, and it is only on approaching the crest of the fold in the lower part of the Continental formation that we begin to find seepages. The fact that part of this good exposure has been comparatively recently washed by the sea is scarcely a good reason for the present entire absence of all traces of oil.

Wild-catting in the underlying formations has given oil occasionally in small quantities in the Spirialis Beds, and in the Lamna Beds, but not in the intervening strata, although many seepages are known from the Spirialis and in the western hills from the Lamna Beds. The older rocks do not seem therefore of value, as possible producers, and as far as the Apsheron Peninsula is concerned, it is the upper beds that must be prospected for, and the part of the peninsula remaining is that N.E. and E. of Balakhani. The most important structure in this direction is a N.E.–S.W. fold, passing through Kala, half-way towards Holy Island from the Surakhani fold. Here Apsheron beds are exposed, but so far as I know no definite results have been obtained. The lesson of Holy Island seems to be that one must be prepared for the possibility of unconformity between the Apsheron and the underlying formations with the absence of some of the favourable reservoir rocks. These remarks, let me hasten to add, are not intended as prophetic.

Outside the Apsheron Peninsula similar conditions prevail in the lower part of the Kura plain, *i.e.*, near the mouth of that river and extending northwards to the Transcaucasian Railway at Adji-Kabul. This region may be regarded as the continuation of that of Shemakha. It is marked by a line of mud volcanoes and seepages which extend out to sea to the island of Kurinsky Kamen. Unfortunately, much is hidden by recent deposits, but it is clear that well-defined folding occurs, sometimes with Apsheron or Upper Freshwater beds on the crest; at others deeper horizons are exposed. The so-called Salian Steppe on the right bank of the river has attracted much attention, but suffers from lack of exposures. It has not yet been definitely tested to below the Apsheron. The Babazanan Hills north of the river have Akchagyl and Freshwater beds on the crest of a well-marked fold, which is still unproven.

Terek District.

The Northern Caucasus, of which the Grozny district is the principal oil area, gives us in place of the Apsheron type of succession the more normal one of Mediterranean and Sarmatian beds overlain unconformably by the Akchagyl. In the old Grozny field we have a good example of an asymmetric anticline, in which the Akchagyl surrounds an elongated compressed dome of Middle and Lower Sarmatian rocks with the transition to Mediterranean just exposed on the apex. The main oil formation is here the Chokrak, not exposed on surface, which is over 1200 feet in thickness, and consists of shales and sandy clays with sandstones, calcareous sandstones and dolomites. It belongs to the second Mediterranean stage. From the fact that in the neighbouring Sundja Hills where this formation is exposed it is devoid of oil it has been argued that the oil is derived from below by migration. This may be the case, and since the distribution of the oil in the old Grozny field has been found so sharply defined by dip faults there is probably reason in it. The dome is curved slightly and the central portion which is limited by dip faulting at its ends is thrust forward. The northern side is the steep one dips reaching 90° at times, while to the south they do not exceed 20–30°. There are seven oil sands and several stray sands :—

SUCCESSION IN OLD GROZNY FIELD (AFTER KALITSKI).*

Akchagyl Stage.	Limestone, conglomerate of limestone boulders, calcareous sandstone and clayey sand and calcareous clay.		With :—Cardium dombra, Andrus. ; C. Nikitini, Andrus. ; C. radiiferum, Andrus. ; Mactra subcaspia, Andrus. ; M. Karabugasica, Andrus. ; M. acutecarinata, Andrus. ; M. Inostranzevi, Andrus. ; Potamides caspius var. rotundispira, Andrus. ; Clessinia sp. ; Helix 2 sp. *Thickness up to* 425 *m.*
		Unconformity.	
Middle Sarmatian.	Beds with remains of fish and cetaceæ.	Gray shales (non-calcareous) with occasional thin shaley limestones.	With :—Algæ ; abundant fish remains ; Cetaceæ. *Thickness* 40-320 *m.*
	Cryptomactra Beds.	Calcareous clays with beds of limestone in upper part.	With :—Cryptomactra pes anseris, Mayer ; Coralliodendron sp. ; in lower part of series : Cardium Fittoni, Andrus. ; Trochus, sp. ; Algæ. *Thickness* 95 *m.*

* See *Mém. Com. géol. Russ. n.s.* **24** (1906).

Lower Sarmatian.	Mactra fragilis Beds.	Calcareous clays with interbedded soft, chalky marls.	With : — Mactra fragilis, Lask. ; Cardium sub-Fittoni, Andrus. ; C. aff. Suessi, Barb. ; Cardium, sp. ; Modiola, sp. ; Buccinum Verneuilli, d'Orb. ; Trochus Rollandianus, d'Orb. ; T. angulato-sarmates, Sinz. ; Cerithium, sp. ; Bulla truncata, Ad. ; B. sp. ; Algæ ; fish scales. *Thickness* 17 *m.*
	Syndesmya reflexa Beds.	Calcareous shales with numerous limestone beds.	With :—Syndesmya reflexa, Eichwald. *Thickness* 43 *m.*
Transition from Sarmatian to Mediterranean.	Spaniodontella Beds.	Shales, sandy clays, clay sandstone, calcareous clays and sandstones, limestones. The sandstones are *water bearing.*	With :—Spaniodontella pulchella, Baily ; Sp. umbonata, Andrus (?). *Thickness* 50 *m.*
	Chokrak Beds.	Shales, sandy clays, clay sandstones, sandstones, calcareous sandstones, limestones (often concretionary), dolomite. The sandstones carry *oil.*	With :—Spaniodontella intermedia, Andrus. ; Sp. crassideus, Andrus. ; Sp. sp. ; Mytilus sp. ; Corbula sp. (?) ; Donax sp. ; Mactra Basteroti var. Konkensis (?) ; Syndesmya sp. (?) ; Leda sp. ; Pholas sp. ; Trochus sp. ; Buccinum sp. ; Spirialis sp. *Thickness* 370 *m.*
Mediterranean.	Spirialis Beds.	Black shales, limestones, black concretionary limestones, dolomites.	With :—Spirialis sp. ; Pecten sp.

The old field is well defined and offers no scope for new developments, which must be looked for in similar structures in this district, of which one, known as the Bellik field, has already been developed. This lies some ten miles from the old field towards the east, on the other side of the town. It is distinguished by more symmetry than the old field, northern dips ranging from 20–40°, whilst southern vary from 20–35°. Again we have the Sarmatian inlier surrounded by Akchagyl.

There are many seepages in adjoining localities from the Black Hills in the south, to Gudermes on the railway east of Grozny, where favourable structure occurs at Isti-su, and towards the west in the Terek Hills, which like the Sundja range, is an anticline resembling the Grozny fold. Here the most important area appears

to be at Voznesensk, not far south of Mozdok, on the river Terek, to which it is connected by pipe-line. One well is stated to be producing and this forms the basis of one of the concessions which the Russian government is prepared to grant.

All these hill ranges parallel the main range of the Caucasus, and this district offers prospects of locating favourable structures further north where the geology is concealed by recent deposits. It is probable that it is the most promising of any in the Caucasus.

Kuban District.

Passing westwards again little of interest is found on entering the Kuban territory before reaching the so-called Maikop district, although it is worth recalling that gas has been struck to the north, near Stavropol. Beginning with Maikop, or more correctly, in the Neftianaia-Shirvanskaia area, we find extending north-west a number of oil occurrences connected with slightly disturbed Tertiaries, dipping away from the Cretaceous hills upon which formation they lie unconformably. Thus we have the more recently worked field at Shirvanskaia, and the older pools at Ilsky and Kudako. At Maikop the main oil is associated with erosion valleys in a series of foraminiferal clays and marls of Middle Oligocene age, which are filled with a conglomeratic belonging to the overlying Maikop formation, dark shaley marls with beds of coarse sand and sandstone becoming conglomerate or gravel in places. This formation is Upper Oligocene and Lower Miocene in age, and is characterised by fish remains. It seems the only source available for the oil, which is found also in sand lenses in the Maikop formation itself, as distinct from the fillings of the erosional valleys. The lower oil has a gravity of ·840, as compared with ·940 for that in the higher sands. :—

SECTION AT NEFTIANAIA-SHIRVANSKAIA (AFTER CHARNOTSKI).*

Meotic.	Congeria Panticapea Beds	Dolomitic limestone; at base dark shales.	With :—Congeria Panticapea Andrus., small Hydrobia.
		Unconformity.	
Upper Sarmatian.	Mactra Caspia Beds.	Conglomerates, gravel, sands. Thin beds of clay. A few thin partings of ferruginous sandstone, shell beds, gypsum.	With :—Mactra Caspia Eichw. *Thickness* 25–30 *m.*

* See *Mem. Com. geol. Russ. n.s.* 47 (1909).

Middle Sarmatian.	Beds with typical Mid. Sarmatian fauna.	Dark gray clays. At top shell bed.	With :—Tapes vitaliana, d'Orb. ; Cardium obsoletum, Eichw. ; Mactra, sp. ; Trochus, sp. ; Turbo Omaliusi, d'Orb. var. rugosa Sak.
	Cryptomactra Beds.	Dark gray shales. At base thinly laminated gray marls.	With :—Cryptomactra pes anseris, Mayer ; Trochus, sp., Coralliodendron ; fish remains and plants. *Thickness small.*
Lower Sarmatian.	Beds with Lower Sarmatian fauna.	Shell limestone.	With : — Ervilia trigonula, Sak ; E. podolica, Eichw. ; Cardium cf vindobonense, Partoch ; Bulla Lajonkaireana, Bast.
	Beds with fish and plant remains.	Dark gray marls with beds of thinly laminated gray shales.	With :—Fish and plant remains and a few Mactra, sp. *Thickness* 400-500 *m. in East.*
Middle Miocene.	Spaniodont Beds.	Compact marly limestone with porous layers.	Spaniodont, *sp.* *Thickness* 10-15 *m.*
	Spirialis Beds.	Dark shales and yellow gray marls.	Spirialis. *Thickness* 200-400 *m.*
	Chokrak Beds.	Sandy and Bryozoa limestone. Shell beds, dark marls.	Ervilia praepodolica, Andrus. ; E. pusilla, Phill. ; E., sp. ; Corbula gibba, Ol ; Leda fragilis, Chemn. ; Arca turonica, Duj. ; Cardium Hilb., Andrus. ; C. sp. ; Venus, sp. ; Cytherea, sp. ; Trochus quadristriatus, Dub. ; Tr. Chokrakensis, Andrus. ; Tr. pictiformis, Andrus. ; Tr. sp. ; Nassa Dujardini Desh. ; N. obliqua, Hilb. ; N. restitutiana, Font. ; Cerithium Cattleyæ, Baily ; C. scabrum, Ol ; C. sp. *Thickness* 20-25 *m.*
Lower Miocene. Upper Oligocene.	Maikop Formation.	Dark shales, not effervescing with acid. Beds of coarse grained sand and sandstone, in places passing into gravels and conglomerates. The rocks are usually impregnated with oil. Fish remains. *Thickness* 225 *m.* (*Neftianaia*).	
Middle Oligocene.	Foraminiferal Beds.	White clays and marls. Beds of bituminous shales.	Foraminifera. *Thickness* 800 *m. in W. and centre,* 200 *m. in E.*
Lower Oligocene.	Pecten Bronni Beds.	Greenish gray clays.	With : — Pecten Bronni, Mayer ; P. sp. ; Lucina rectangulata Hofm. ; L. gracilis, Nyst. ; Nucula, sp.

		Unconformity.	
Senonian.	Chalk and marl.	White chalk with occasional beds of dark clay and coarse sandstone.	With: — Inoceramus, sp.; Austinocrinus Erckerti, Dames.
		Unconformity.	
Aptian.	Sandy clayey beds with Ammonites.	Dark sandy clays with beds of coarse sandstone.	With:—Terebratula Dutemplei, d'Orb.; T. sp.; Rhynchonella, sp.; Thetis minor, Sow.; Parahoplites aschiltensis, Anth.; P. Abichi, Anth.; Lytoceras, sp.; Acanthoceras Martini var. Caucasica, Anth.; Belemnites semicanaliculatus, Blainv.

At Ilsky and Kudako oil was obtained from the same horizon, but now no data are available as to whether similar erosional valleys were the favourable feature. At any rate the first Russian gusher was struck at Kudako (Krymskaia) in February, 1866, at the shallow depth of 70 feet, and is said to have given an ultimate yield of a million poods. The oil was ·840–·865 in gravity, and therefore must have been similar to that of Maikop. Between the two, and worked in the early 'eighties, lies Ilsky, where two horizons were productive, the Maikop sand giving light oil and a heavier oil came from an overlying dolomite, either belonging to the Chokrak or of Sarmatian age.

The conditions are obviously analogous, and while it must be remembered that a whole number of other seepages along this zone have been unsuccessfully wild-catted the chances of striking fresh similar pools, which so obligingly come in with big gushers at shallow depth, and then allow themselves to be prospected down the dip, have not been exhausted. There remain also the chances, as yet untested, of deep tests on folds which exist down the dip, such as that in middle Sarmatian at Apsheronskaia, where depths of 3000 feet would have to be reckoned with, but other factors bearing an oil accumulation would then come into play than the simple structure of overlap at the present wells.

Beyond Krymskaia the Maikop and overlying formations sweep round the Cretaceous end of the Caucasus, and disappear near Anapa on the south side. They plunge north-westwards beneath the Pliocene and Pleistocene to form the Taman Peninsula. This we have already seen resembles the Apsheron, both as regards the variety of directions of folding and resulting topography, and as regards the great development of surface indications of oil, especially

in the shape of mud-volcanoes, which general conditions are shared with the corresponding Kertch peninsula across the Straits. This naturally led to early attempts to drill and prior to the gusher at Kudako, in 1864 drilling was started on the Taman, and since that day many attempts have been made to develop it. It is now abundantly clear that what fails is anything to act as a satisfactory reservoir. The surface formations are all without good sands and are usually Pliocene, so that deep tests would be necessary in many of the localities, which otherwise look interesting structurally, for the Sarmatian and underlying rocks have not yet yielded good pay, although in many cases oil of high grade has been struck, usually from the Sarmatian or Spirialis. It seems evident that quite big explosions from mud-volcanoes may have their origin from insignificant sands, in fact this type of phenomenon is a witness rather to the preponderance of a clay facies.

Georgia.

Along the southern side of the Caucasus seeps are common, and many interesting structures await proper testing. Few localities, however, hold out great hopes of big supplies of oil.

In the Kutais Government in the Ozurgety district, we find oil occurring in the equivalent of the Maikop series and in the Chokrak. At Yakobi, on the railway occurs a large deposit of tar in a sandstone younger than Pontian. The structure in places is good, but intrusions of volcanics prejudice the oil prospects. In the Tiflis Government again many seepages occur, both in Sarmatian and in the Eocene which often yields a high grade oil with paraffin, as at Ildokani in the Telav district. Many of the areas which can be better studied as in the Kakhetya Mountains, or at Chatma, are, unfortunately, so unfavourable from a structural point of view, that they tend to discredit some of the areas on the steppes where only seepages can be seen. It may be that descending the Kura valley towards the Caspian more favourable conditions are likely to occur.

Geological Succession at Chatma (after Kalitski) :—*

Akchagyl.	(*a*) Conglomerates, sandstones and clays.	With : — Cardium dombra, Andrus. ; E. cumuchicum, Andrus. ; C. trinacria, Andrus. ; Mactra Ososkovi, Andrus. ; M. Venjukovi, Andrus. ; Potamides caspius, Andrus. ; P. disjunctoides, Sinz.
	(*b*) Clays with sands.	
	(*c*) Sandstones and sands with clays and conglomerates.	

* See *Bull. Com. géol. Russ.*, Vol. XXVI. (1907).

	Unconformity.	
Upper Sarmatian.	(*a*) Clays ranging from green and red to gray and yellow with sand and sandstone partings. The clays are gypseous.	
	(*b*) Green and gray clay. More sandstone than in overlying.	With:—Fragments of Unio sp.; Planorbis, sp.
	(*c*) Sandstone predominating over green clays. Part of the sandstone is oil-bearing forming the first horizon at Kidurma, Paatov's property, etc. There are beds of lignite.	With:—Unio, Anodonta and Paludina in the clays. Mactra caspia, Eichw.; M. cf. crassicollis, Sinz.; more rarely M. crassicollis, Sinz.; Solen sub-fragilis, Eichw.; Hemisinus (Melanopsis), sp.; Unio sp.; in the sandstones.
Middle Sarmatian	(*a*) Brown and gray clay and sandstone.	
	(*b*) Similar beds with limestone partings and calcite. The clays are separated by thick sandstones. This includes the second oil sand. It gives rise to a mud volcano.	
	(*c*) Brown and gray clay.	
	(*d*) Oolitic limestone, passing into sandstone. Some brown clays.	With: — Mactra ponderosa, Eichw.; Cardium Fittoni, d'Orb.; C. obsoletum, Eichw.; C. protractum, Eichw.; Tapes sp.; Donax sp.; Turbo Omaliusii, d'Orb. var. rugosa, etc.
Unknown.	(*a*) Very hard limestone.	Full of small mactras (?).
	(*b*) Green and red clays with sand and sandstone partings. Beds of lignite.	In clay are frequent Unio. The sandstone with casts of undetermined Mactra.
	Unconformity.	
Mediterranean.	Sandstone and clays.	
	Unconformity.	
	Light gray shales. Large concretions of limestone.	Cryptodon sinuosus, Don (?), Spirialis sp.

The structure is a fold in which a cross fault has thrown the southern part towards the south-west, and its north-eastern flank forms the prolongation of the south-western wing of the northern portion. Strikes are W.N.W.–E.S.E. on the northern side, and N.W.–S.E. on the south, dips on either side varying up to 70°.

Transcaspia and Turkestan.

The Transcaspian continuation of the Baku fields is best known at the locality of Nafta-Dagh, twenty miles W.S.W. of the station of Balla-Ishem, on the Central Asiatic Railway, and at the island of Cheleken, south of the town of Krasnovodsk. The latter has yielded a considerable production from a small area in the south-west corner, the former has not yet done so. The formations are more continental than at Baku, and determination of the age is difficult. The structure on the whole is well seen as a result of the desert conditions prevailing and it is much broken by minor faulting in all directions. On the island of Cheleken oil has been obtained in many localities by the Turkomans, but the only production under modern conditions was in the south-western corner, and that principally from the trough fault of Ali-Tepe in Apsheron beds. These overlie the Akchagyl, and a continental formation of unknown age, which is well seen further east in the Chokrak dome towards the centre of the island, where it consists of sands and red marls. These latter beds are much fissured and, owing to the scour of desert sand, these fissures often stand up as thin veinlets of ozokerite in a very characteristic manner, and seepages occur in various places, often with signs of older workings. The big production at Ali-Tepe appears to have come to an end, and it is not easy to see where more of a similar nature can be found. There remains, however, the possibilities of deep tests, *e.g.*, on Chokrak, for it is unlikely that the oil of the continental formation is indigenous to it. We may gather some idea of the quantity of oil that has here escaped from the remains of Turkoman pits in the Aralo-Caspian deposits. These beds have been rapidly denuded since they rose above the sea, and in many cases the pits, which were lined with reeds, are the only witness to them, and only appear as circular patches on the ground, these being due to the cake of hardened oil, which formed at the bottom of the pit, the rest having been entirely removed by the wind and sand drift. In these Pleistocene beds, too, we find pebbles of very hard ozokerite, which shows that the oil was escaping prior to their deposition. The oil had as much as 5 per cent. paraffin in the shallower wells, but in the deeper sands only 2 per cent. It was accompanied by hot water (52° C.), which caused much trouble. The ozokerite was formerly mined.

The succession, omitting Pleistocene, on Cheleken, is as follows (after Weber and Kalitski)* :—

Baku Stage.	(*a*) Grey and red marls and grey micaceous sands with basal gravel.	With :—Dreissensia rostriformis, Desh. ; Dr. polymorpha, Pall. ; Neritina liturata, Eichw.
	(*b*) Red marl alternating with sand. Black shale.	

* See *Bull. Com. géol. Russ.*, Vol. XXVIII. (1909).

Apsheron Stage.	(*a*) Red marl. *Thickness* 16 *m.* (*b*) Thick black shale, sands, red marl. *Thickness* 175 *m.* (*c*) Compact marl with thin partings of sand (? volcanic dust); black shale; thin sandstones. *Thickness* 207 *m.*	With :—Dreissensia rostriformis, Desh.; Dr. anisoconcha, Andrus; Dr. Eichwaldi, Issel; Dr. latro, Andrus.; Dr. polymorpha, Pall.; Didacna intermedia, Eichw.; D. longintermedia, Andrus.; D. plurintermedia, Andrus.; D. subintermedia, Andrus.; D. turkmenica, Andrus.; D. Lörentheyi, Andrus.; Monodacna Sjögreni, Andr.; M. bacuana, Andr.; M. Isseli, Andr.; M. lævigata, Andr.; M. gösdekiana, Andrus.; Apsheronia propingua Eichw.; A. eurydesma, Andrus.; Micromelania dimidiata, Eichw.; M. sp.; Celekenia Ivanovi, Andrus.; Streptocerella Sokolovi, Andrus.; Neritina liturata, Eichw.; Limnea voluta, Andrus. (?).
Akchagyl Stage (?).	Fish beds. Light grey shaley marls with beds of black shale and partings of volcanic dust. *Thickness* 42 *m.*	With :—Quantities of fish scales, some bird bones and bones of a mammal.
Red Beds.	Alternating grey and green sands. With Brick-red marl.	
Aligul Beds (? Palæogene).	Green limestone, very hard calcareous sandstone and olive-coloured shale.	

Nafta-dagh has the same continental beds exposed and other localities to the south-east are known. Prospecting is difficult, and anything like a satisfactory investigation would be very expensive. On present information this district offers poor prospects.

In Turkestan proper both the Oxus and Jaxartes valleys have oil shows from a Lower Tertiary formation, known as the Fergana stage, this taking its name from the important valley of the Jaxartes, north of the Tian Shan mountains, where are situated the towns of Kokand, Andizhan and Namangan. Near the latter town the valley is widest as the river receives the important tributary from the north, known as the Naryn. It is only the margin of this plain where the Fergana stage is seen, and so we have two widely-separated belts of seepages on the north and south side, respectively, which unite to the east. A considerable number of seepages are known along this belt from Kulmen, at the west end of the northern strip, through Changyr-Tash on the east to Chap-Kyldyk at the

west end of the southern portion. The best-known area is that at Chimion, not far from New Margelan, and west of here south of the railway station of Melnikovo, where production on a small scale has been obtained for many years. The succession of the Tertiary rocks at Maili-Sai, according to Golubiatnikov* is as follows :—

First Stage.

(*a*) Light brown sandy clay and conglomerates. *Thickness* 1000 *m.*

(*b*) Brick red clay, sand, sandstones and conglomerate. *Thickness* 100 *m.*

(*c*) Variegated sandy clay, sand, sandstone and conglomerate ; alternating red, green and blue-gray. *Thickness* 28 *m.*

Second Stage.

(*a*) Red clay with partings of sand, sandstone and marl at top. Upper clays have a constant but poorly preserved fauna including a cast of bivalve resembling a Panopea 4 cm. in length, a cast of Turritella, cylindrical tubes of Serpula (?), fish teeth. In the middle of the formation is a marl with large oysters. *Thickness* 58·6 *m.*

(*b*) Greenish-gray calcareous clays, marl and limestone with Pecten at top and a rich fauna in middle of Leda, Pecten, Lima (?), Lucina gigantea Desh., Cardium, a small oyster, Fissurella, Dentalium, Turritella, Bryozoa, fish scales and teeth. *Thickness* 25·8 *m.*

(*c*) Bituminous dark fish shales containing concretions at top with large Isocardia, and containing throughout abundance of fish teeth and scales, the scales resembling those of Meletta sardinites, and M. osmeroides. At base are flat oysters. *Thickness* 33 *m.*

(*d*) Sand, sandy clay and at base conglomerate. *Thickness* 10 *m.*

Third Stage.

Fergana Stage.—Limestone, marl, clay, sand and conglomerate. In lower part mainly Gryphæa Romanowskii Böhm. In this stage are three thick limestones. *Thickness* 60 *m.*

Fourth Stage.

Sand, clay and limestone with small Gryphæa and large sized Gasteropods. Casts of Ampullaria (?), Conus (?). At base are sandy clays, sands and conglomerates. *Thickness* 150 *m.*

The oil-bearing rocks are Lower Tertiary in age and apparently contain oil only in the folds nearest the valley, but not towards the Cretaceous hills. It is further of interest that only where faulting is prevalent do we find seepages.

This interesting formation covers large areas, thus to the south, not far from the Oxus, where it forms the frontier of Afghanistan, near the town of Shirabad, seepages are connected with an asymmetric fold in exactly similar rocks to those seen near Chimion, and again in the valley of the Zarafshan in between, whilst northwards it is said it covers large areas associated with oil indications to the south of Lake Balkash. The formation above described is very different from what we have been considering in the Caucasus, and

* See Höfer-Engler. Das Erdöl.

has yet to be properly investigated, suffering in this respect on the score of accessibility. The oil has paraffin and a gravity of ·860, and resembles more that of Cheleken and Emba than Baku. Whether the fish shales overlying the Fergana stage could have been the source of the oil, due to their becoming involved in complex faulting, is a possible explanation of its origin, but in view of its similarity to that of Emba, where there seems no doubt of a deeper source for the oil, possibly in the sandy clays of Jurassic age, if not even in the Permian, this may be doubted. This question has more than an academic interest, for the scattered occurrences of oil reported over the wide area intervening between the Caspian and the Fergana districts, such as in the Turgai Province and elsewhere, suggest that the oil possibilities of this vast Territory are by no means unworthy of closer investigation and the oil may be from an older formation than is commonly supposed. The not inconsiderable occurrence of oil and gas on the south-eastern shore of Lake Baikal is connected with a fault in which Tertiary and Jurassic rocks are let down against the Archaic which forms the shore. Ozokerite forms a conspicuous accompaniment of the occurrence which fact again requires to be remembered in attempts at correlation of these various occurrences.

Emba District.

Whatever may be the possibilities of the more remote parts of Turkestan and Transcaspia as regards oil production the Emba district situated to the north-east of the Caspian, of which we have an excellent account in Mr. Holiday's paper, read before this Institution, can claim to be good producing oil lands. More recently important developments have taken place at Iman-Kara, 120 miles east of Makat. Throughout this area we have the Jurassic and Cretaceous rocks lying unconformably on the Permian, which, as we have seen, is petroliferous over a wide area further north-west. The oil sands are low down in the Cretaceous or in the Jurassics, and particularly in view of the faulty and disturbed nature of the geology the oil can well have been derived from these Permian rocks, which, of course, underlie the whole area. This disturbed nature of the ground renders the distribution of the oil pools erratic, particularly when much of the region is masked by recent deposits, and introduces difficulties in the development of the field. Had it not been that the war stopped development there is little doubt much more substantial results would have been achieved.

Volga District.

The Permian itself, when uncovered by more recent formations, which can retain the oil, is not favourable as an oil rock, owing to

its porous nature. The main function of the Permian is that of a percolator through which the oil from the underlying Carboniferous and Devonian shales can ascend to accumulate in the more favourably disposed younger formations. The enormous quantities of these shales that exist at workable depths on the Volga, at Ukhta and elsewhere, will doubtless some day be utilised as a source of oil, and have been worked to a certain extent in the more accessible parts during the occupation of the Caucasus and Don territory by Denikin. The principal centre is Kashpur (Simbirsk Government), on the Volga, although some work was done in the Tver Government, mainly on marsh deposits. The yield at Kashpur is stated to be 5–17 per cent. of tar.

Ukhta District.

At Ukhta the shales (Domanik), which are Upper Devonian, are said to cover an area of 300 square miles, but whether they would ever pay to work in such an inaccessible district is questionable, and moreover, the content is not high. The Devonian rocks are let into Silurian shales by a trough fault, and are folded into an anticline, the oil occurring in sands underlying the shales. The test drilling in this formation has not shown the sands very prolific, although the oil has 12 per cent. of benzine and a gravity of .881 with a paraffin content of 1.25 per cent.

Conclusion.

This paper attempts to correlate the widely distributed oil occurrences of Russia, so as to draw out the possibilities of the country as a whole as an oil producer. The older and better-known fields should recover part of their former production when re-equipped and organised on business lines, particularly if the technical side receives the serious and systematic attention which is necessary, notably in such matters as dealing with the water shut off. It is, however, to newer areas that one must look for future developments.

It is disappointing that so little in the way of new structure has been developed near Baku. Of course, there is little hope for anything in the formation below those at present producing, and the principal development of Pliocene rocks, which might conceal hitherto untapped oil pools, lies on the eastern end of the Apsheron Peninsula and to the west around the lower part of the Kura river. Both these areas deserve more attention than has hitherto been devoted them. Elsewhere in the Caucasus the Grozny (Terek) region offers most inducement to the prospector; already new pools have been proved and a serious geological survey should endeavour

to link up this area with that of the Emba field. The Kuban district offers prospects of similar finds to that known as the Maikop field. The southern side of the main ridge is less promising, unless concealed pools lie towards the Caspian end.

On the Asiatic side too little is known to give much clue for immediate prospecting, but the scientific basis for such would clearly seem to lie in following up the important developments in the Emba field, and this both north-westwards into European Russia and into Asia. It is true that the Fergana pools have never been found very prolific, still they need more testing and we still have to find out whether there are any prospects of oil from deeper sands, within reasonable depths. Thus the Cheleken gushers of pre-war days ought to be regarded as indicators only of deeper oil. Whether such has been retained in workable pools is quite impossible to say at present, but in the writer's opinion it is the most important question that future oil geologists will have to solve. Should it be found to be the case the field thrown open to legitimate "wild-catting" is very great.

DISCUSSION.

Mr. F. M. Penney, in opening the discussion, said one of the first points to which he wished to refer was that the author had seen what he spoke about in the paper. He not only knew Russia very well, but also the other oil-producing countries of the world. He remembered that he first had the pleasure of making the author's acquaintance in the Caucasus in 1910. Mr. Madgwick had then just come back from a visit round Fergana, Tashkent and Bokhara, places in which very few English people had ever set their foot. He did not propose to attempt to follow the author in his wanderings over the enormous territory he had covered, but only to refer to that portion of it that he had seen himself. The author had not mentioned anything about Sakhalin. It had been established on very good authority that oil existed in North Sakhalin. Mr. Beeby Thompson mentioned this fact in his book, and a Russian mining engineer who was the head Government Engineer in the North Caucasus, who had lived in Sakhalin for a great many years, told him that oil existed there. The second proof he desired to mention was in connection with Kalujskaya, near Ekaterinodar. The author had stated nothing about the find that was made there in 1912 or 1913. Those were the only two omissions the author had made. Passing on to that part of the Kuban district where the Maikop field existed, the author made the very interesting statement that the main oil was associated with erosion valleys

in a series of foraminiferal clays and marls of Middle Oligocene age. The point he wished to put to the author was whether he could not concede that the main oil is associated with an ancient river bed, and not erosion valleys. The point upon which he based this hypothesis was, that a monocline existed and, running obliquely across it, was a tortuous line of oil varying from 100 to 200 yards wide, which had already been proved for a distance of one mile and probably extended much farther. He believed that it was not an ordinary erosion valley at all but an ancient river-bed disturbed by the last thrust that came in post Middle Miocene times from the north-east, which tilted up the strata to their present angle, and produced the results as they exist at the present time. If the author agreed, he thought it would have been established that a most extraordinary form of the occurrence of oil existed in this case. Passing along the Caucasus the author stated that Voznesensk was a very promising place. Personally he was in agreement with what the author stated in regard to the line of foothills in the North Caucasus, but, from the experience obtained by a Company by which he is employed, Voznesensk is not the promising place the author imagined. The Spies Petroleum Company put down, within the last three or four years, two wells in that district to a depth of 1,800 feet, and all they obtained was hot water. Passing further along, he desired to mention that the Grozny field was still producing very well indeed. He did not know the latest figures, but he believed that last summer it was producing at the rate of 7,500,000 poods per month, which was 120,000 tons per month, which, under the conditions of difficulty existing in regard to supplies and bearing in mind also that practically no drilling had been done, was a very good result indeed. Passing further along towards the East, he agreed with the author that Isti-su was a most promising field of the future. The author had referred to the gas that was, struck at Stavropol. A friend of his, who was now in Russia, assured him that the two wells that had been drilled there had not been drilled in the right place.

Mr. A. Frank Dabell said he desired to endorse all that the previous speaker had said in regard to the paper, but he wished to deal with it from a more practical point of view. The author had attempted to correlate the oil fields over a vast empire. Apart from the fact that in the country with which the paper dealt there was no incentive to establish that co-relation, the fact had to be accepted that, so far, it had not been possible to establish continuity between the Baku oil fields, *i.e.*, Sabunchi and Surakhani, a distance of only five miles apart. Again it had not been found possible to establish any continuity at Grozny between the old and the new field at Bellik, a distance of ten miles, and the same remarks applied

to the Maikop field, where it had been impossible to establish continuity between Shirvansky and Khadijenskaya, a distance of eight to ten miles. Those were the points which naturally appealed to those who were responsible for putting the oil into the reservoirs there.

The author states: "At Maikop the main oil is associated with erosion valleys in a series of foraminiferal clays and marls of Middle Oligocene age, which are filled with a conglomeratic belonging to the overlying Maikop formation." Those who had worked at Shirvansky knew that the oil is there obtained from the porous *débris* of a subterranean river bed; and he suggested that once that fact was established, it only needed a trained thinker fully to appreciate the governing conditions. The most accomplished trained thinker on the field was the geologist Sara, and it was he who advanced the theory. Once the theory was advanced, the proof followed quickly. There was the tortuous river bed, in which, at the curves gravel was coarser on one bank than the other, and where the old river had run straight, there sectionally one obtained a sand lense; in other words, the slope of the banks on both sides was the same. By careful and intelligent study of the sand and gravel brought from the river bed, it is now possible to estimate where a curve would occur. The latest book published described Maikop in the following manner: "A good example of oil in an unconformity on a monocline is found in the Maikop field of Russia, where strata of Upper Oligocene and Lower Neocene age dipping 7 to 10°, rest unconformably on, or overlap Cretaceous strata."

That describes a river bed. The failure to appreciate that it was a river bed in the first place was a costly error. He did not in any way intend to press that particular point, for the reason that the only persons inculpated were those who had the courage of their convictions to write down or to publish that which they thought. He therefore passed the matter over lightly because, unless geologists had the courage of their convictions and gave practical men established bases to work upon, no progress would be made.

Dr. Dvorkovitz said he much appreciated the opportunity of of joining in a discussion with *confrères* in the petroleum industry, with which he had been associated since 1879. When he first went to Baku, in 1882, petroleum was produced at Balakhany, Sabuntchi, and a small production at Bibi-Eibat. A well-known European geologist then considered that no oil would be obtained in Romany and Surakhani, which districts are at present highly productive. The paper read this evening was the most able paper it had ever been his good fortune to listen to, particularly from the point of

view of the collection of geological data, and it would undoubtedly serve as a model for all papers of the kind. So long as the geologist had not settled in his mind the origin of petroleum, whether it was found *in situ*, or whether it was due to migration, great difficulties would be experienced in following his advice. Once the chief point had been decided, whether the oil had been formed *in situ* or by migration, it would be easier to take the advice of geologists in connection with boring operations. The question was raised in 1900 at the first International Petroleum Congress, where Professor Engler presented a paper advocating the formation of petroleum *in situ*, while he (Dr. Dvorkovitz) presented a paper in favour of the migration theory. Why was it that in Baku there were enormous accumulations of oil, which had been proved to be the case during the last fifty or sixty years, and why was there a difference between the oil at Grozny and Baku ? Dr. Day, the chief of the Geological Department at Washington, had followed up the migration of oil from Texas to Pennsylvania, and had proved that the different character of the oil was due to its migration from one district to the other. He had made a great many investigations of the various strata through which the oil had passed, and had established what was called the "filtration theory." Professor Kharitchkov had come to the conclusion, after careful examination, that the origin of the two oils at Grozny and Baku was the same. Personally, he believed that the oil was formed from coal. A careful examination of the Donetz coal basin, just to the north and west of Grozny proved, that it contained enormous deposits of anthracite, the proportions being about 65 per cent. of anthracite and 35 per cent. of coal. Anthracite was coal which had lost all its hydrocarbons. Professor Bergius had proved that, under pressure, coal was transformed entirely into oil. The whole of the oils which came from the anthracite deposits had migrated from Donetz Basin, through Grozny to Baku. It would be found that the Baku oils were of a high degree of viscosity, the asphaltic portion having been left at Grozny. Pure oil was obtained from Baku, which did not contain asphalt. The same remarks applied very much to the anthracite deposits in Pennsylvania and the respective oils obtained in Pennsylvania and Texas. If the theories that he had stated will be accepted, namely, that oil was formed from coal deposits, and that the oil migrated, it explains much of the difference which at present existed among geologists from the point of view of showing that oil could be found in one or other strata, the Eocene, the Miocene, and so on. At present there was no geological strata in which oil had not been found. He had also had an opportunity of studying closely the Borneo oils, the Indian oils and the deposits of lignite coal in Burma and he again found a very close relationship between them. He thought

it would be a very valuable work if some scientist would take up the relation between the anthracite deposits and the oil deposits, and calculate the quantity of anthracite which existed in the world. Enormous asphalt deposits exists also in Germany and France; in the latter country a heavy oil having been found at Pechelbronn (Alsace). Personally, he thought it was not formed *in situ*, but that it was the result of migration. If geologists would work more closely with chemists, he believed much helpful information to the industry would be obtained. At the same time, the work that had been done by the author was of very great value, as he had brought together all the available data in regard to the oil fields of Russia. He desired, in conclusion, to make a few remarks with regard to one field which the author had mentioned, and which, personally, he believed would prove in future to be one of the biggest oil fields in Russia, namely, the Ural Emba field. He was a member of the Bolshevik Committee which had had before it the question of the laying down of a pipe line from Mokata to Saratov, on the Volga, a distance of 800 versts. In order to come to a decision on the subject it had been necessary to obtain the latest data, which had been obtained by very eminent practical geologists in regard to the investigations made in the Ural Caspian fields. The question was considered of laying down a 6-inch pipe line, which would probably be increased to a 12-inch pipe line, as they were quite sure that those fields would be of enormous importance in connection with the development of the Russian petroleum industry.

Mr. E. A. Evans said that as it had been suggested that those who lived on the field could not correlate the various types of oil which occurred in this district, he claimed some indulgence for himself in acknowledging that he was a little mystified in regard to three statements which occurred in the paper. The statement made on page 12, in connection with the Surakhani field, that the deeper the well the higher the gravity. Reference was also made to the fact that in the upper strata the oil contains 65 per cent. of kerosene, and 5 per cent. of paraffin. Personally, he wondered whether the gravity rose by virtue of the gradual diminution of the kerosene, or whether another type of hydrocarbon was obtained as the well went down, or yet again whether the oil was more richly charged with asphaltic matter. The author referred to the oil from the lower strata in the Kuban district having a gravity of 0·840, as compared with 0·940 in the higher sands. The order was reversed in that case, and no mention was made of the presence or absence of kerosene or paraffin wax. In the Maikop field a low-gravity oil was obtained at a depth of 70 feet; he imagined, therefore, that a higher gravity was obtained at greater depths. The fact that the low gravities were obtained in the higher portions of

one field, while the order was reversed in the other field, called for an explanation.

Mr. T. G. Madgwick, in reply, after expressing his thanks for the kind remarks which had been made by the various speakers, said that Mr. Penney had added to the information contained in the paper, by calling attention to one or two places to which he (the author) had omitted to refer. Mr. Penney had drawn a distinction between erosion valleys and ancient river beds. Personally, he did not think he would draw that distinction. It was a long time since he was in Maikop, but his impression had always been that what existed there was the ancient course of the Pshekha. Mr. Dabell's remarks on that point had added very much to the available information on this very interesting occurrence. It was precisely such practical details, with which the geologist ordinarily would not be acquainted, except through the help of the man on the field, which enabled him to learn the actual conditions in regard to the occurrence of oil. He had no idea that the little details which clearly indicated the presence of an old river deposit had been so carefully worked out by the men on the field. He thought that deserved great praise. He was surprised to hear Mr. Penney say that Voznesensk was not a very promising place, because he read that it was being pushed very much by the Soviet Government. He agreed with Mr. Penney's view regarding Isti-su, although he had never been on the actual spot itself. Then, in regard to the distinction raised by Mr. Dabell, between co-relation from a geological point of view, and the identification of oil sands, he personally thought they were two distinct things altogether. Unfortunately, it was never possible to say that an oil sand in different pools was exactly the same. If the oil occurred in recognisable geological horizons over a wide area, then it was possible to talk of correlating the oil sands, but where merely lenticular sands existed, without other means of identification, the co-relation from the oil point of view was impossible. Geological co-relation, quite apart from this identification of the individual sands, was of primary importance, and he was pleased to see that of late years it had become more recognised than it was when he first went to Baku.

In reply to Dr. Dvorkovitz's most interesting remarks, he desired to suggest to that speaker that it was not a young man who was required to carry out the work of describing the theory he had put forward, of the association of anthracite and oil. He remembered hearing Dr. Dvorkovitz talk about that subject at the end of 1903, and he thought an effort should be made to induce Dr. Dvorkovitz not to allow his matured consideration of the subject to be lost; and he hoped Dr. Dvorkovitz would write a paper on it.

In reply to Mr. Evans, he was afraid he was not prepared to say

whether the differences in the oil on going from the higher horizons at Surakhani, down to those encountered at Balakhani, were due to any gradual diminution of kerosene. It might be so, but he did not think it was due to any essential difference in the chemical composition; it was purely a question of gravity. In the Kuban district at Maikop the lower oil was, of course, the lighter. That, he presumed, was due to the fact that it had been so effectually sealed that it had not been subject to any oxidising influences, or loss from evaporation, whereas oils that occurred in the small sand formations above, which are exposed in the ravine, were oxidised products. The quantities in such upper sands were quite small compared with the very large yields that had been obtained from the deep sand. It was the deep sand that was the only important matter in that district.

On the motion of the President, a very hearty vote of thanks was accorded to the author for his interesting paper, and the Meeting terminated.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

A MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, January 9th, 1923, PROF. J. S. S. BRAME, President, occupying the Chair.

The following Members of Council were present :—Sir Frederick W. Black, Dr. W. R. Ormandy, and Mr. H. Barringer.

The President, before calling upon Dr. Ormandy and Mr. Craven to read their paper, said he desired to direct the attention of members to the fact that, under the new Bye-laws, nominations for the Council had to be received before the 31st January next, and each nomination had to be signed by at least ten members, one of whom proposed the candidate and the other nine of whom supported him. Nomination forms had been prepared and could be obtained from the Secretary.

It afforded him much pleasure to call upon Dr. Ormandy to read the paper which had been prepared by Mr. Craven and himself. It would be within the recollection of the members that a very valuable contribution on a similar subject to that with which the present paper dealt was read by Dr. Ormandy and his associates a few months ago, and the present paper was an extension of the work then brought before the Institution.

The following paper was then read :—

Further Investigations into the Physico - Chemical Significance of Flash-Point Temperatures.

By W. R. ORMANDY, D.Sc., F.I.C., F.C.S., M.I.A.E.,
and
E. C. CRAVEN (Members).

IN a previous paper the question of the flash-points of a large number of bodies was dealt with and the various relations discussed. The effects of variation of pressure and of composition of the surrounding atmosphere were briefly considered. It was shown that :—

1. At the flash-point in air all hydrocarbons possess approximately the same vapour tension.
2. Increase of pressure raises flash-points.
3. Replacement of air by oxygen lowers flash-points.

For the further investigation of these relations work has been

carried out mainly on heptane, toluene and ethyl alcohol as representing respectively a typical paraffin hydrocarbon, aromatic hydrocarbon, and an aliphatic alcohol. The character of these liquids has already been dealt with in the previous papers already mentioned.

The present work divides itself naturally into four parts :—

(*a*) Determination of vapour tensions.

(*b*) Flash-points at reduced or increased pressures.

(*c*) Flash-points in mixed gases.

(*d*) Flash-points where vapour-air mixture is further heated.

The accurate determination of the vapour pressure of these

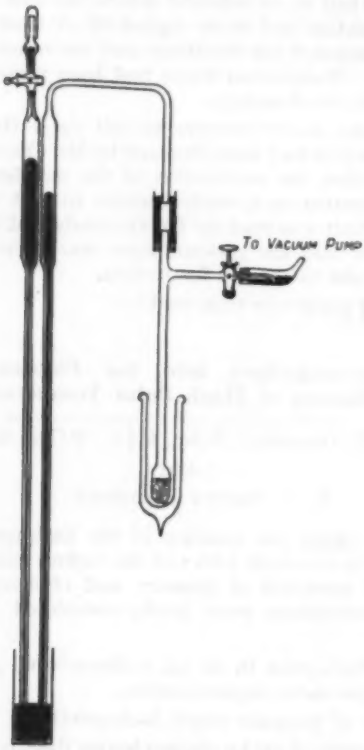

FIG. 1.

APPARATUS FOR VAPOUR TENSIONS AT LOW TEMPERATURES.

bodies at temperatures below 0° C. proved a matter of very considerable difficulty. For higher temperatures the method of Ramsay and Young gave figures in excellent agreement with the results of Young and others on the three bodies mentioned. Below about 5 mm. pressure the method proved very difficult to work, especially in the absence of a powerful mercury pump.

After the trial of various forms of apparatus, the form shown in the diagram (Fig. I.) was adopted.

The bulb was first about three-quarters filled with the liquid under test, and cooled down to about −40° C. The apparatus was then evacuated down to about 1 mm. pressure by means of an oil pump. The bulb was then allowed to warm up to a little over room temperature so that a small quantity of liquid distilled over on to the surface of the mercury in the gauge. The bulb was then cooled to room temperature and the pumping out continued. The vapour of the liquid sweeps out any residual air left in the first exhaustion.

If the temperature now be kept constant the indicated vapour pressure will be observed to increase, amounting perhaps to 50 per cent. of the initial indicated pressure. This appears to be very largely due to dissolved permanent gases, since on repeated pumping out this increase gets smaller and smaller, until the observed pressures, after waiting say 15 minutes, are constant. Even after reaching this stage, however, the evolution of gas does not appear to be finished, since after standing 24 hours an increase in pressure of the order 0·5—1·0 mm. may be noticed.

After all the gases are removed the bulb is cooled to a temperature below that at which the first reading is required. The whole apparatus can then be allowed to warm up slowly, and the pressure readings taken. The mean results obtained are tabulated below :—

TABLE I.

Vapour Pressures in mm. Hg.

Temp. °C.	Heptane.	Toluene.	Ethyl Alcohol. (99·8% vol.).	Ethyl Alcohol. (95·0% vol.)
−40	0·30 ·8	0·25 ·4	0·65	0·50
−35	0·55	0·45	0·95	0·75
−30	1·05 1·7	0·70 ·9	1·35	1·10
−25	1·90	1·15	2·10	1·80
−20	3·00	1·70	3·10	2·80
−15	4·35	2·45	4·35	4·05
−10	6·30	3·55	6·30	6·10
− 5	8·80	5·00	8·85	8·75
0	11·80 12·5	6·95 7·1	12·60	12·20
5	—	9·95	18·20	17·40
10	—	13·65	24·60	24·20
15	—	17·25	33·00	32·80

The vapour pressures for heptane and toluene when compared according to Ramsay and Young's law, agree to about 0·4 mm., which difference appears partly to be due to a real divergence of one or both from the simple law. The curves for alcohol (absolute and 95 vol.) are, of course, away from the hydrocarbon curves, but the two curves run smoothly beside each other.

Determinations of the vapour pressure of toluene were made by J. T. Barker, who used the streaming method. Electrolytic oxygen was employed and the amount of toluene estimated by combustion on copper oxide. He gives the following values as compared with the present work :—

TABLE II.

Temp. °C.	Barker. Vapour Press.	Present Work. mm. Hg.
0	6·86	6·95
—20·3	1·74	1·67
—21·0	1·61	1·58

The vapour pressure of ethyl alcohol at low temperatures has been determined latterly by Drucker and by Ephraim. The results marked with asterisks are by Drucker :—

TABLE III.

Temp. °C.	Vapour Pressure. mm. Hg. Present Work.
* 0	12·24 — 12·60
*—24·8	1·72 — 2·02
—29·9	1·08 — 1·45
*—32·1	·83 — 1·20
—32·8	·83 — 1·13
*—34·4	·66 — ·99
—37·7	·52 — ·77
—39	·46 — ·71
—40·2	·41 — ·50

The Annual Tables may be consulted for literature relating to the figures quoted.

DETERMINATION OF FLASH-POINTS UNDER REDUCED PRESSURE.

For these determinations the previously-described flash-point instrument was used. The bell tube was fitted into the test tube by means of a rubber bung, through which passed a glass right-angle bend, so that a reduced pressure could be obtained in the test tube by means of a water pump. At pressures below 200 mm. of mercury the flashes became extremely weak, so that definite results could not be obtained.

The results obtained have been plotted, and the following figures read off the smoothed curves :—

TABLE IV.

Lower Flash-Points.

Pressure mm. Hg.	Toluene.	Heptane.	Alcohol. (100% vol.).	Alcohol. (95% vol.).
760	10°	— 2°	10°	15°
700	8°	— 3°	9¼°	14°
600	4½°	— 6°	8°	12°
500	1°	— 9°	6°	10°
400	—2½°	—12½°	3°	7°
300	—6°	—15½°	— ½°	3¼°
200	(—9)°	—	—5°	—1°

We give below various calculations based on these curves, but it was found later on that the results under reduced pressures are, to a considerable extent, vitiated by the presence of gas in the purified liquids. This was not apparent until the pressure work was being proceeded with, and trials were made with "de-gassed" liquid. Probably more accurate results could be obtained from the exterpolation of the pressure results. The curves of the pressure results for toluene, heptane, and alcohol have been exterpolated in Fig. II., and the experimental points at lower pressures are shown

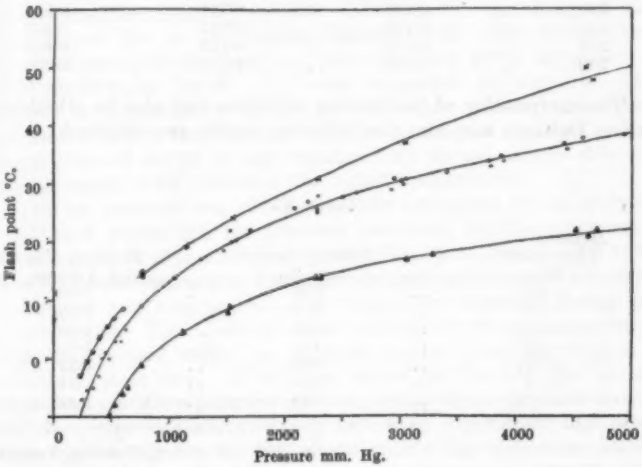

FIG. 2.

FLASH POINTS UNDER VARYING PRESSURES.

Toluene experimental points o
Alcohol (100%) „ „ ×
Heptane „ „ Δ
Points below 760 mm. in glass apparatus on liquid not "degassed."

also. It will be noticed that the results for toluene and heptane fall in line fairly well with the high-pressure results, but that with alcohol the low-pressure results are too low.

Reference was made in the previous paper to a constant $R = \frac{\text{Flash-point °K.}}{\text{Boiling pt. °K}}$ For all hydrocarbons in air at normal pressure this was found to have round about the value of 0.736 for normal pressure. Introduction of OH, CO groups, etc., appears to raise this constant. The value of R at reduced pressures can naturally be calculated from our figures if the boiling points of the liquids are known under reduced pressure. These boiling points we have taken from Young's vapour pressure curves, and the values of R so calculated are given in the following table :—

TABLE V.

Pressure mm. Hg.	R		
	Heptane.	Toluene.	Alcohol.
750	0·734	0·738	0·807
650	0·733	0·739	0·812
550	0·737	0·741	0·816
450	0·740	0·745	0·822
350	0·747	0·752	0·825
250	0·759	0·762	0·830

The composition of the limiting mixtures may also be calculated, using Dalton's law, and the following results are obtained :—

TABLE VI.

Heptane. Flash-point °C.	Total Pressure mm. Hg.	% Heptane Vapour by Volume.
—17½	230	1·50
—15	315	1·38
—12½	393	1·30
—10	475	1·33
— 7½	556	1·33
— 5	640	1·38
— 2½	720	1·42
		% Toluene Vapour by Volume.
Toluene.		
— 7½	250	1·66
— 5	323	1·55
— 2½	396	1·54
0	468	1·48
2½	541	1·49
5	615	—
7½	688	1·69

			% Alcohol Vapour by Volume.
Alcohol 99·8 *Vol.* %.			
— 5	.. 205	..	4·32
— 2½	.. 254	..	4·10
0	.. 313	..	4·03
2½	.. 380	..	4·00
5	.. 458	..	3·96
7½	.. 563	..	3·77
10	.. 744	..	3·32
			% Alcohol Vapour by Volume.
Alcohol 95·0 *Vol.* %.			
0	.. 220	..	5·55
2½	.. 273	..	5·35
5	.. 331	..	5·27
7½	.. 404	..	5·08
10	.. 491	..	4·94
12½	.. 611	..	4·55
15	.. 755	..	4·32

Determination of Flash-Points under Increased Pressure.

The pressure in an engine cylinder when starting from cold may amount to several atmospheres. It was therefore thought advisable to carry flash-point determinations up to a total pressure of 6—7 atmospheres. It was obvious that some form of metal apparatus would have to be employed for this purpose. The apparatus shown diagrammatically in Figs. III. and IV. was designed and constructed for us by Messrs. Ricardo, Ltd. The temperature of the interior of the flash cup was originally given by means of a thermocouple, but it was found impossible to keep the joint tight. A thermometer pocket was therefore soldered into place as shown, and a thermometer with a small bulb employed. The large mass of metal of high conductivity should ensure that the thermometer truly indicates the liquid temperature.

The air pressure was obtained in the apparatus by an ordinary cycle foot pump and the pressure measured by the compression of an air space over a refined spindle oil in a calibrated glass tube. The oil was withdrawn at frequent intervals and heated up in order to remove any volatile matter it might have absorbed during the experiments. The oil absorbed air slowly from the commencement, and after several weeks' use appeared to be absorbing oxygen at much the same rate. In order to correct for this and also for any slight change of temperature of the air space the air pressure reading on the gauge was always taken before an experiment and after, allowing 15 minutes for the oil to drain. The difference seldom exceeded ½ per cent., and the mean reading was taken as corresponding to the air pressure as shown by the barometer. The pressure during the experiment was calculated by Boyle's Law and the results were probably correct to about 2 per cent. As a 10 per cent. change of pressure usually changes a flash-point by 1° C. the error is of no moment. It can be shown, moreover, that

the correction of the calculated pressure for the hydrostatic head of oil in a suitably proportioned gauge is negligible.

Considerable difficulty was experienced in maintaining air-tight the various joints on the instrument. The spark lead was originally a stout steel wire running through an ebonite plug, but this was a continual source of trouble, and was later replaced by a stout platinum wire fused through glass. The joint was made by a rubber ring screwed down by the original gland screw.

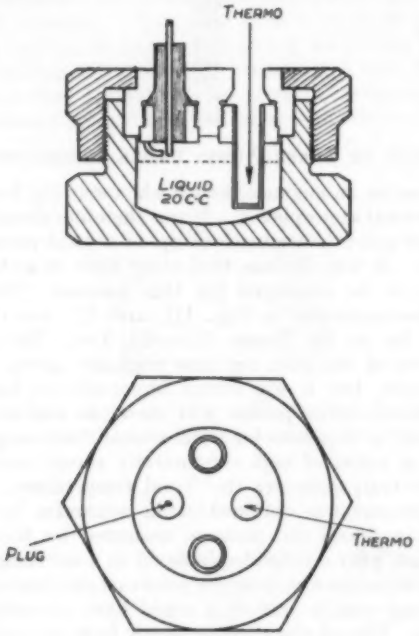

FIG. 3.

APPARATUS FOR FLASH POINTS AT HIGH PRESSURES.

For temperatures above atmospheric the apparatus was heated up in an air bath as indicated in sketch. For lower temperatures cooling was effected by means of carbon dioxide snow. The manipulation of the instrument was as follows for hydrocarbons:—The cup was cleaned and dried and a spoonful of granular soda-lime introduced. The desired volume of sample (usually 1 c.c.) was pipetted in and the apparatus assembled. The gauge reading was taken, and air pumped in to about the desired pressure. The

instrument was then cooled to well below the expected flash-point and then allowed to warm up slowly (about 1 degree in 2 minutes). The sparking key was depressed at each $\frac{1}{2}°$ rise, the gauge reading being first noted. After the flash the air pressure was released and the gauge allowed to drain 15 minutes and read again as already explained.

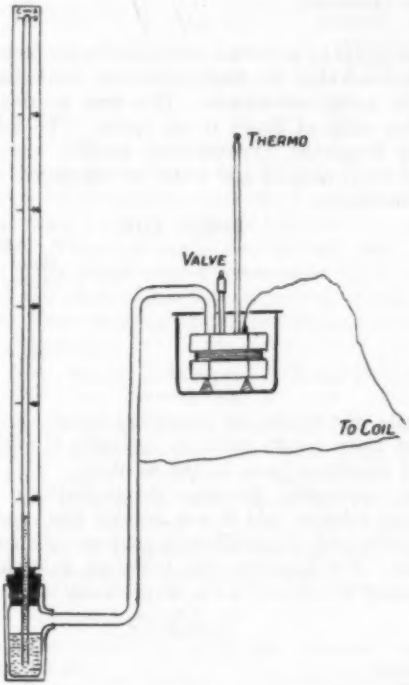

FIG. 4.

APPARATUS FOR FLASH POINTS UNDER PRESSURE.

Roughly to Scale.

In some cases calcium chloride or filter paper was used to spread the liquid and in other cases the liquid alone was tried. No differences were traced in this respect.

Several tests were made at atmospheric pressure in order to compare the present apparatus with the glass tester; the results were as follows:—

TABLE VII.

	Flash-Point °C. Glass Tester.	Pressure Apparatus
Naphthalene	84	81
Anilin	72	72
Turpentine	36	34
Amyl Alcohol	44	44
Borneo Extract	50	46
Kerosene (American)	55	53
Kerosene (Borneo)	44	42

10 c.c. of the liquid to be tested was taken in the pressure apparatus. It will be noticed that the flash-points are somewhat lower on the whole in the metal instrument. This was, no doubt, partly due to the higher ratio of liquid to air space. The following figures, interpolated from the experimental results, were obtained for mixtures of ethyl alcohol and water as compared with those previously published :—

TABLE VIII.

Strength Alcohol. % wt.	Flash-Point °C. Metal Tester.	Glass Tester.
100	9½	10
95	13	14½
90	14½	16½
85	16½	17½
80	18	18½
75	20	21

Here, again, the results are somewhat lower; but we shall show shortly that these results must be seriously in error owing to the presence of dissolved gases in the alcohol.

The first systematic pressure determinations under pressure were done on toluene, and it was noticed that considerable differences were obtained when different amounts of toluene were taken for the test. For example, the following smoothed curves were obtained using 10 c.c. and 1 c.c. respectively :—

TABLE IX.

Pressure Atmospheres.	Flash-Point °C. 10 c.c. used.	1 c.c. used.
1 atmos.	9	9½
2 „	16	20
3 „	20½	26½
4 „	24	31
5 „	27	34
6 „	29	37½

Trials were made with 1 c.c. of toluene using nothing else in the flash cup and also using calcium chloride, soda-lime, and filter paper in turn. The effect of doing several flash-points on the same 1 c.c. of liquid was compared with changing the liquid after each flash, but all the results were alike within the usual experimental limits.

Some of the pure toluene was now put under the vacuum of an oil pump and boiled at room temperature for 1 hour until all dissolved gases appeared to be removed and the ebullition became "bumpy." About 5 per cent. of the toluene distilled off in the process.

Flash-points were now taken on the "de-gassed" toluene, and the following results taken from the smoothed curves :—

TABLE X.

Pressure.	Flash-Point °C. 1 c.c. in cup.	10 c.c. in cup.
1 atmos.	10	10
2 „	20	20
3 „	25½	26
4 „	30	30½
5 „	33½	34
6 „	—	37

The results agree very well with each other, and, it will be noticed, with the results using 1 c.c. of ordinary toluene—*i.e.*, pure toluene not "de-gassed." This is as might be expected, and it is obvious that the use of a low liquid-vapour space ratio will to a very large extent wipe out the effect of small quantities of volatile impurities.

In all, 34 flash-points were taken on toluene, and the results were found to fit the formula.

$f = 36{\cdot}9 \log. P - 97{\cdot}6$ Where f = flash-point in °C. and P = total pressure in mm. Hg.

The mean divergence of the observations from this curve is 0.6° C.

Pressure-flash-point curves were taken on other liquids fractionated to a high degree of purity in the ordinary way. After "de-gassing" the flash-points were found to be much higher. It is not worth while reporting the low results under pressure, but the flash-points at atmospheric pressure may be noted as corrections on our previously published values.

TABLE XI.

Lower Flash-Points at 760 mm. Pressure.

	Glass Tester. Ordinary.	Glass Tester. "De-gassed."	Pressure Tester. Ordinary.	Pressure Tester. "De-gassed."	R.
Benzene	—12	—	—	—10	·746
Toluene	10	10	10	9	·736
Cyclo-hexane	—17	—	—	—12	·738
Methyl-cyclo-hexane	— 4	—	—	— 2½	·730
Tetraline	70	78	—	78	·736
Turpentine	38	38½	—	39	·727
Heptane	— 1	— 2	—	— 1	·734
Methyl Alcohol	— 1	6	—	11	·840
Ethyl „	11	13	—	14	·818
Propyl „	24	—	—	27½	·817
Butyl „	38½	—	—	39	·800
Amyl „	44	—	—	45	·776

The lower flash point constant " R " is given in the last column, and is calculated from the flash-point of the " de-gassed " material in the steel apparatus, using a mean boiling point, as only 1 c.c. of liquid was used. The general trend of the corrected values of R., for hydrocarbons, is to bring these nearer to .736. It will be noticed that in the case of methyl alcohol the lower flash point is 5° C. higher in the steel apparatus than in the glass tester. This appears to be due to methyl alcohol flame being very sensitive to the cooling effect of the walls.

All the bodies tested in the pressure apparatus gave results fitting formulæ of the type

$$f = n \log P - K,$$

with the exception of ethyl alcohol (absolute and 95 per cent. volume), and with two kerosenes tested also the flash-point-log P relations were not quite linear.

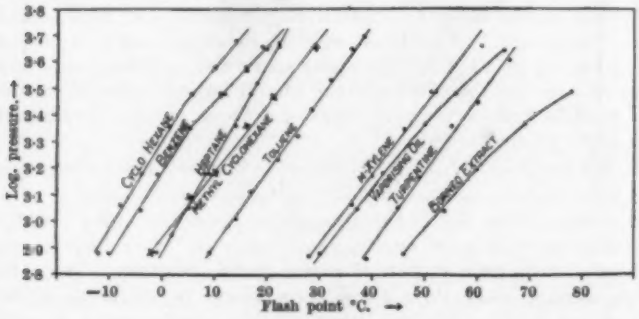

FIG. 5.

FLASH POINTS OF HYDROCARBONS UNDER PRESSURE.

In Figs. V. and VI. we give the curves of the flash points plotted against the logarithms of the corresponding pressures. It will be noticed that these are practically all straight lines, and, moreover, with the exception of heptane, the liquid hydrocarbon curves are all inclined at the same angle and the alcohol curves have another constant angle of inclination. The slope of the curve appears to change when solidification occurs, as with cyclohexane or benzene. This uniformity of slope is a somewhat unexpected result, and no interpretation has as yet been found for it.

In the case of the kerosenes it is obvious that it is the ratio of liquid to air which affects the slope of the curve or the linear nature of the flash-point-log-pressure relationship. The curvature is more marked at the higher pressures where the flash point is higher, and where consequently a greater proportion of the more volatile fractions is evaporated off. The results on vaporising

oil where varying amounts of liquid are taken show this also to be the case. Where large amounts of oil are used the slope of the curve is that for a pure hydrocarbon, but where small amounts are taken and the air space becomes relatively large, the flash-points become higher since a larger proportion of the liquid has to be evaporated.

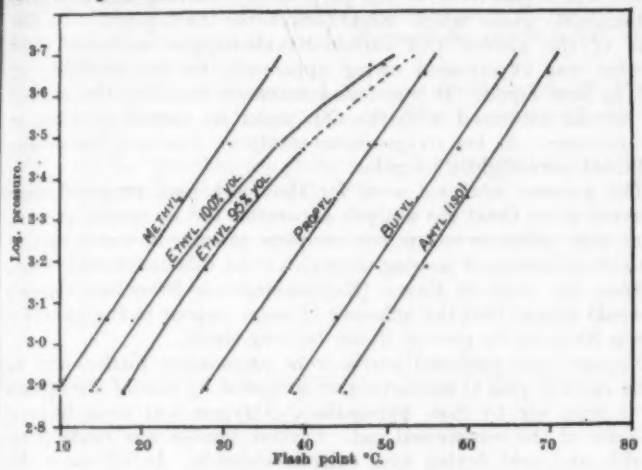

FIG. 6.

FLASH POINTS OF ALCOHOLS UNDER PRESSURE.

The following table is constructed from the smoothed curves :—

TABLE XII.

Flash Points of Liquids under Pressure.

	°C.					
Pressure atmos. =	1	2	3	4	5	6
Benzene (solid)	—10	—½	5		Liquid.	
„ (liquid)	Solid.		5	11	16	20
Toluene	9	19½	26	31	34½	37
m-Xylene	28½	40½	47½	52½	56	59
Cyclo-hexane (solid)	—12	—4	1	Liquid.		
„ „ (liquid)	Solid.			5½	10	14
Methyl-cyclo-hexane	—2½	9½	16½	21½	25½	28½
Turpentine	39	49½	55½	60	63½	66
Heptane	—1	8½	13½	17½	20	22½
Methyl alcohol	10	20	26	30½	33½	36
Ethyl „	14	23½	31	37	42½	47½
Ethyl „ (95 vol.)	18	27	34½	40	45½	50½
Propyl „	27½	38	44½	48½	52	55
Butyl „	39	48½	54	58	61½	64
Amyl „	45	54½	60½	65½	68	70½
Borneo Extract	46½	59	68	76½	—	—
Vaporising oil 10 c.c.	30	42	49	56	61½	65½
„ „ 5 c.c.	30	43½	51	58	63	67
„ „ 1 c.c.	30	45	53	60½	65½	70

Flash-Points in Mixed Gases.

For these determinations a side tube was blown on to the bell tube, so that the mixed gases might be passed into the tube from time to time in order to ensure the constancy in composition of the required atmosphere. The bubbling of the gases through the liquid was hoped to serve the purpose of removing any dissolved inflammable gases which might affect the flash-point. In the case of the alcohol and carbon-dioxide-oxygen mixtures some trouble was experienced owing apparently to the solubility of CO_2 in that liquid. It was found necessary to allow the alcohol to become saturated with the CO_2 under its partial pressure in the mixture. At low oxygen concentrations, however, the results obtained were slightly irregular.

The gaseous mixtures were for the most part prepared over mercury in an Orsat gas analysis apparatus, but no special precautions were taken to ensure the complete absence of water vapour with the exception of passing through a 10 in. calcium chloride tube. From the work of Eitner (Explosionsgrenze Brennbaren Gase) it would appear that the influence of water vapour in the quantity it was likely to be present would be very small.

Nitrogen was prepared partly from ammonium nitrite, and in some cases N plus O mixtures were prepared by partial absorption of O from air by Sod. pyrogallate. Oxygen was used from a cylinder of the compressed gas. Carbon dioxide was made from marble and acid drying over calcium chloride. In all cases the pure gases, when tested by the Orsat, showed a purity of 99.7 per cent. upwards.

The following notes were taken of the appearance of the flashes under the altered conditions :—

Appearance of Flames.

1. *Tetralin.*—(*a*) Spark bright, and above 50 per cent. O_2 the nickel points were "capped" by a bluish flame, and the thermometer rose 5-15° C. Carbon was deposited in higher concentration of O_2.

2. *Turpentine.*—(*b*) Ordinary yellow spark. Combustion occurred at nickel points with 40.0 per cent. O_2 at first flash, but did not occur afterwards.

3. *Heptane.*—(*a*) Ordinary yellow spark. In a number of cases an appreciable wait period was noticed between the passing of the spark and the occurrence of explosion. These cases of slow combustion cannot be regarded as the true flash-point, but it appears probable that the intensity of the spark may cause sufficient local heating to start the combustion, although below the correct flash point temperature.

4. *Toluene.*—Burning at the points commenced at a concentration of 50 per cent. O_2. Carbon was deposited at each flash.

5. *Alcohol.*—Flame pale blue and very indistinct. It was most difficult to tell the flash-point with this substance, as the flame could not always be seen. Alcohol was characterised by a specially loud "bumping" noise which took place on passing a spark when in the neighbourhood of the flash-point, although no visible combustion took place, and no rise in temperature was observed after the spark had passed.

"Bumping" normally started when the concentration of O_2 was about 20 per cent., and took place to a lesser extent with toluene and tetralin.

The results obtained are given in the following tables, and are plotted graphically in Figs. VII.–XII.

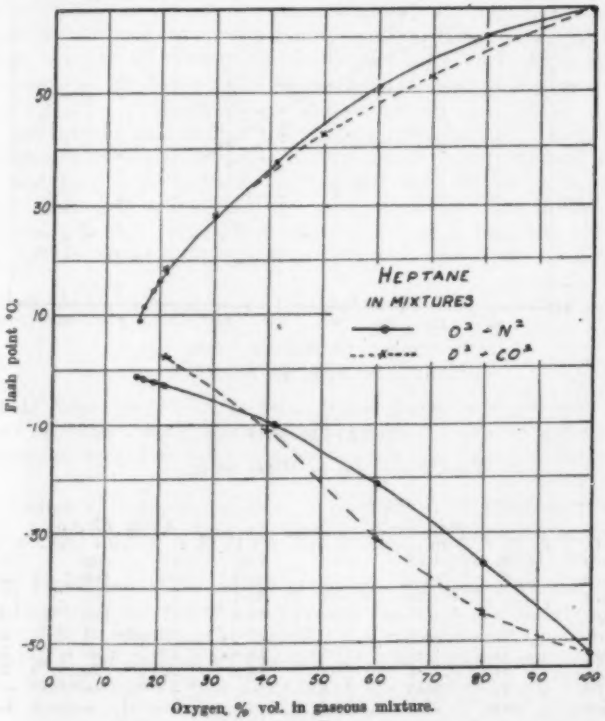

FIG. 7.

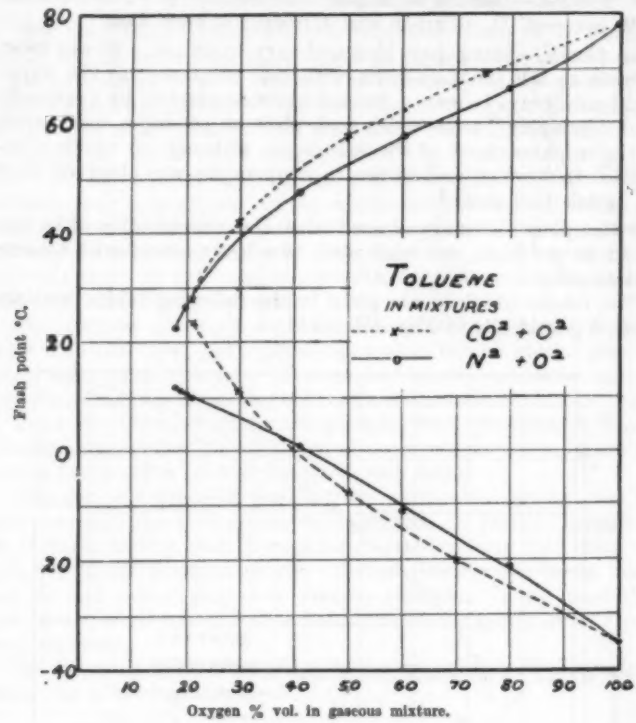

FIG. 8.

TABLE XIII.

Flash Points, etc. in Mixed Gases.

Toluene in Oxygen and Nitrogen.

	Lower Flash.			Upper Flash.			
% O.	Fl. P. °C.	Vap. press.	% vap.	% O.	Fl. P. °C.	Vap. press.	% vap.
100·0	—36	0·39	0·05	100	77	260	34·2
80·3	—21	1·60	0·21	80·3	66	180	23·7
60·5	—11	3·30	0·43	60·5	57	125	16·4
40·8	1	7·5	0·99	40·8	47	80	10·5
21·0	10	13·6	1·79	21·0	29	35	4·6
20·0	11	15·4	2·03	19·8	26	30	3·95
18·7	11	15·4	2·03	18·2	22	25	3·30
17·0	12	16·3	2·15	—	—	—	—
16·8	12	16·3	2·15	—	—	—	—
<16·8	no flash.			<18·2	no flash.		

Toluene in Oxygen and Carbon Dioxide.

100	—36	0·39	0·05	100	77	260	34·2
70	—20	1·74	0·23	75	69	198	26·0
50	— 7	4·38	0·56	50	58	130	17·1
30	11	14·6	1·92	30	42	65	8·6
21	24	27·5	3·62	21	28	35	4·6
19	no flash.			<21	no flash.		

Heptane in Oxygen and Nitrogen.

100	—53	(0·2)	(0·03)	100	65	252	33·2
80·3	—36	0·48	0·06	80·3	60	209	27·5
60·5	—21	2·75	0·36	60·5	51	146	19·3
40·8	—10	6·30	0·83	40·8	37	82	10·8
21·0	— 4	9·35	1·23	21·0	17	32	4·2
18·1	— 3	10·00	1·32	19·6	16	30	3·95
16·1	— 2	10·75	1·41	18·2	14	27	3·55
15·6	— 1	11·55	1·52	17·4	11	24	3·20
<15·6	no flash.			16·5	8	20	2·65
				<16·5	no flash.		

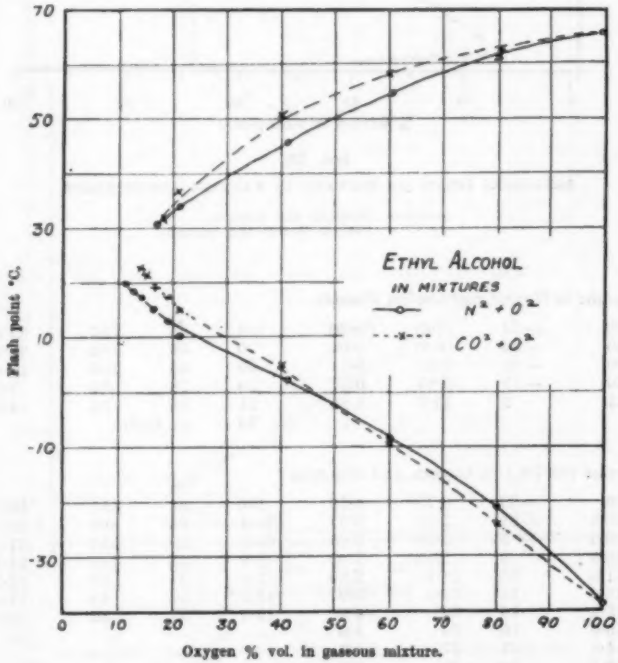

FIG. 9.

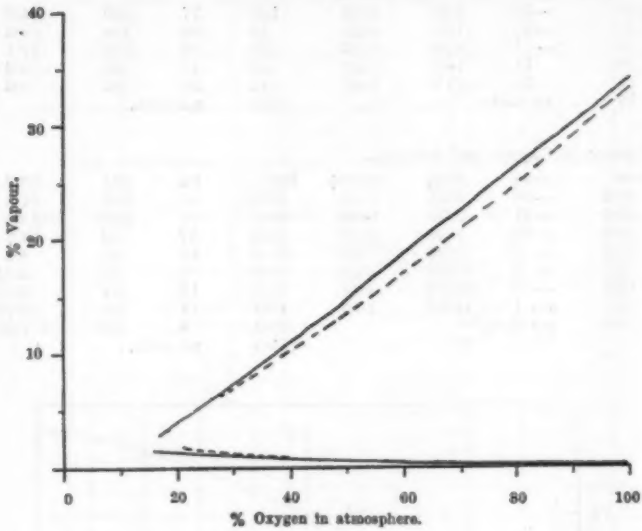

FIG. 10.

EXPLOSION LIMITS OF HEPTANE IN VARYING ATMOSPHERES.

——— Nitrogen and Oxygen.
- - - - - Carbon dioxide and Oxygen.

Heptane in Oxygen and Carbon Dioxide.

100	—53	(0·2)	(0·03)	100	65	252	33·2
80	—46	(0·3)	0·04	70	53	158	20·8
60	—32	0·82	0·11	50	43	104	13·6
40	—11	5·85	0·77	30	28	54	7·1
21	2	14·0	1·84	21	18	33	4·3
				19	no flash.		

Alcohol (99·7%) *in Oxygen and Nitrogen.*

100	—39	0·75	0·10	100	66	450	59·3
80·3	—21	2·85	0·37	80·3	63	400	52·7
60·5	— 8	7·20	0·95	60·5	55	283	37·2
40·8	3	15·8	2·05	40·8	46	185	24·4
21·0	10	24·7	3·26	21·0	34	98	12·9
18·6	13	29·6	3·9	18·0	32	88	11·6
16·6	15	33	4·3	16·0	31	82	10·8
16·0	16	35	4·6	—	—	—	—
14·2	17	37	4·9	—	—	—	—
12·1	19	40	5·3	—	—	—	—
10·9	20	43	5·7	—	—	—	—

Alcohol (99·7% *v.* 1) *in Oxygen and Carbon Dioxide*

100	—39	0·75	0·10	100	66	450	59·3
80	—24	2·25	0·30	80	62	385	50·7
60	— 9	6·70	0·88	60	58	325	42·7
40	5	18·15	2·39	40	51	235	30·0
21	16	35	4·60	21	36	109	14·3
19	17	37	4·90	18	32	87	11·5
16	19	40	5·3	—	—	—	—
15	22	50	6·6	—	—	—	—
14	23 ?	53	7·0	<18	doubtful flashes.		

TABLE XIV.

Various Bodies in Oxygen and Nitrogen.

Turpentine (Pinene fraction 158–160° C.).

Oxygen %		Lower flash-point °C.
100	..	—7
80	..	8
60	..	18
40	..	27
21	..	36
17	..	37
15	..	39
13	..	no flash.

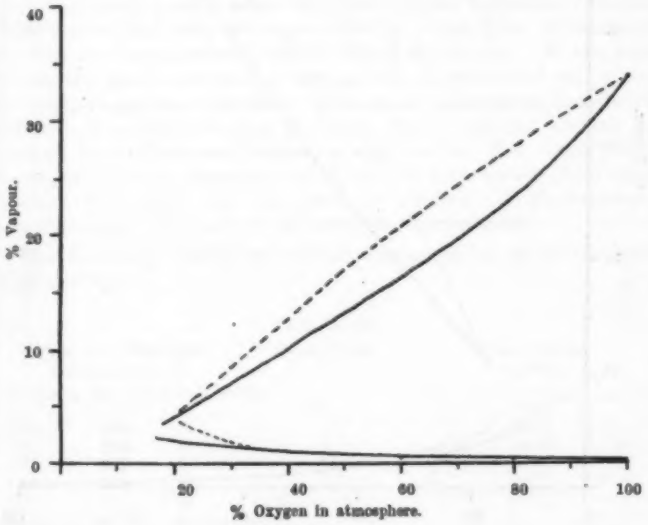

FIG. 11.

EXPLOSION LIMITS OF TOLUENE IN VARYING ATMOSPHERES.

——— Nitrogen and Oxygen.
- - - - - Carbon dioxide and Oxygen.

Tetraline (203–206° C.).

Oxygen %		Lower flash-point °C.
100	..	26
80·3	..	38
60·5	..	51
40·8	..	60
21·0	..	69

Hexahydroxylene (119–120° C.).

Oxygen %		Lower flash-point °C.
100		Below —4·0
80·3		" —4·0
60·5	..	—10½
40·3	..	0
21·0	..	10½

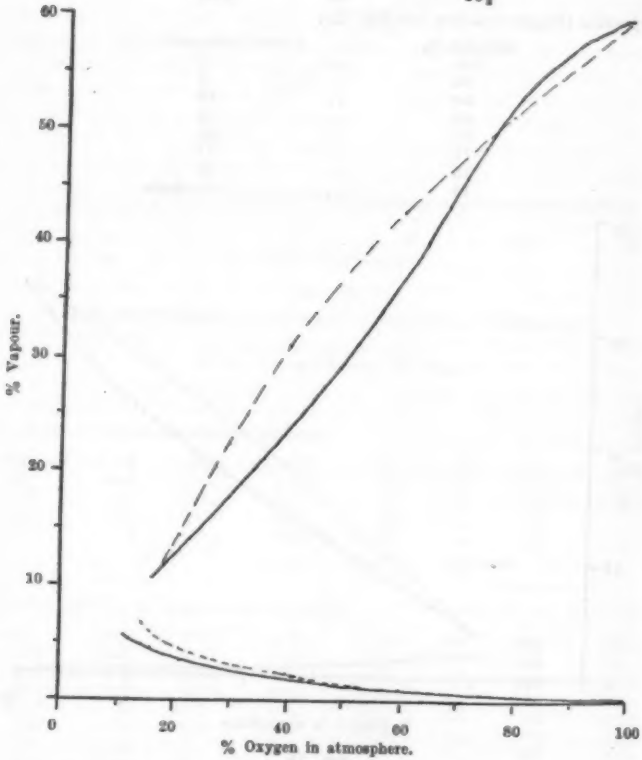

FIG. 12.

EXPLOSION LIMITS OF ETHYL ALCOHOL IN VARYING ATMOSPHERES.

——— Nitrogen and Oxygen.
- - - - - CO_2 and Oxygen.

Alcohol (96·3% vol.).

Oxygen %		Lower flash-point °C.
21·0	..	14
40·8	..	1
60·5	..	—17

EFFECT OF TEMPERATURE ON LOWER LIMIT OF INFLAMMATION.

Some experiments were made with various types of apparatus in order to determine the effect of increasing the temperature of vapour-air mixtures. It was found that, as might be expected, very much weaker mixtures would ignite at higher temperatures than at room temperature.

The method employed was to bubble air through the liquid under consideration, which was allowed to rise slowly in temperature. The mixture then passed to the explosion chamber, which was either at room temperature or heated in an electric furnace where it was sparked from time to time until flame propagation occurred. The experimental results were somewhat erratic, but fairly consistent results were obtained when the mixture was passed through a copper coil to ensure correct temperature of saturation, and a one-inch diameter quartz tube was used as the explosion chamber. This was wound with resistance wire for about 5 ins. of its length so that the temperature could be raised electrically. At the point where the gases entered the tube a plug of glass wool was placed in order to get an even flow. This glass wool was at a sufficient distance from the hot zone to ensure that it did not become hot enough for surface combustion to start on it. The spark points were placed at the opposite end of the hot zone and as little metal allowed to project into the gases as possible. A glass-enclosed thermo-couple was used to measure the temperature.

The following results on toluene appear to us to be the most trustworthy :—

TABLE XV.

Explosion Chamber Temperature °C.		"Flash-Point." °C.		Lower Limit % Vol.
Air speed 20 c.cs. per minute.				
15	..	10	..	1·70
260	..	7	..	1·46
350	..	6	..	1·39
450	..	4½	..	1·26
550	..	1½	..	1·02
Air speed 80 c.cs. per minute.				
15	..	8	..	1·54
260	..	5	..	1·32
350	..	4	..	1·21
450	..	2½	..	1·09
550	..	—1½	..	0·83

If the lower limits be plotted against the explosion chamber temperature approximately straight lines are obtained except at the highest temperatures, where the results are certainly greatly affected by cracking or the like.

This would indicate that in all cases the flame temperature is a constant—namely, about 1800° C. A similar result has been found by Wheeler and Mason (1) for the case of methane-air, and by White (2) for ammonia-air, the approximately constant temperatures being 1400° C. and 1620° C. for the two cases respectively.

Exterpolating we might imagine that where the lower limit became zero the temperature so found would be the ignition temperature and the flame temperature of the vapour since flame would be propagated with the very minimum of stimulus. It will be noticed from the figures given that the lower limit for toluene falls 0.7 per cent. when the air temperature rises 535° C., indicating a zero point at about 1200° C. This hardly appears to bear any relation either to the flame temperature or to the ignition temperature as found by Moore.

It is difficult to form any quantitative theory connecting the various factors which determine the lower and upper explosion limits. The determination of the limits is dependent to a very large extent on the particular apparatus used, so that the results can only be understood as relative.

According to J. Newton Friend (Chemistry of Combustion, 1922) the lower limit mixture depends on a variety of factors, of which the following are said to be the most important :—

(*a*) Calorific value of the gas.

(*b*) Relative volume and specific heat of the diluent.

(*c*) Ignition temperature of the gas.

(*d*) Pressure.

(*e*) Temperature.

(*f*) Proximity and nature of the walls of the enclosure.

Taking these different points in turn, a good deal can be said about each, but such criticism is not wholly constructive.

It has been shown that for paraffin hydrocarbons, from methane up to pentane, the lower limit mixture can be calculated from the empirical formula :—

$$L = K/C.$$

(*a*) Some recent work by A. G. White deals with various hydrocarbons and also ether, methyl and ethyl alcohols, acetone and methyl ethyl ketone, and other bodies. Here, again, with the exception

(1) J.C.S., 1918, **113**, 45.
(2) J.C.S., 1922, **121**, 1694.

of carbon-disulphide, a fair agreement is shown between the observed values for L and those calculated from the net calorific value.

It will be noticed, however, that the molecular weights of the bodies to which this rule has been applied fall within certain somewhat narrow limits; for example:—

In White's work the lightest body used was methyl alcohol mol. wt. 32, and the heaviest toluene mol. wt. 92. When this empirical rule is applied to hydrogen, as is already known, the calculated value for L is seriously in error.

From our previous work on this subject we have shown that for a body of high mol. wt. like naphthalene R is of the same order as for lighter hydrocarbons. Moreover, for kerosene our factor R is the same as for hexane, indicating that even the heavy hydrocarbons in kerosene have a vapour pressure of 12 mms. at their flash points.

There is not the slightest doubt that R would be the same for any pure hydrocarbon, no matter what its mol. wt.; in other words, the lower limit does not continue to fall in the manner prescribed by the calorific law.

However, within the limits of mol. wts. indicated there is no doubt that a considerable correspondence exists between the calculated and observed values for L.

Taking the three bodies dealt with in this paper we find the following figures:—

TABLE XVI.

	Cal. Val.	L Calc.	L Obs.
Alcohol	306 ..	3·46 ..	3·4
Toluene	897 ..	1·18 ..	1·7
Heptane	1072 ..	0·99 ..	1·5

The calculated values are from the formula:—

$$L = K/C \text{ taking } K \text{ at } 1059.$$

(*b*) Coming next to the relative volume and specific heat of the diluent, it is usually stated that carbon dioxide exercises a very much more powerful extinctive effect than nitrogen owing to its greater specific heat.

For the present work it will be seen that when the oxygen concentration exceeds about 40 per cent., carbon dioxide is less effective than nitrogen. In other words, flash-points are lower in carbon dioxide oxygen mixtures than in corresponding nitrogen mixtures when there is less than 60 per cent. of the diluent present. It is difficult to assign any theoretical reason for this phenomenon, but it indicates that facile dicta are likely to be wrong in a subject about which so little is known. Possibly at the increased tempera-

ture of combustion arising from the higher concentration of oxygen, the carbon dioxide will support the combustion of hydrocarbons in a manner similar to that in which magnesium burns in carbon dioxide.

It is known also that the calorific value of a fuel is very nearly proportional to the amount of oxygen required for its combustion. It is obvious, therefore, dealing with the lower limit, that as the specific heat of oxygen and nitrogen are extremely close there is no reason why the lower limit should be any different in pure oxygen or air.

In all probability some of the lower limits obtained in oxygen-rich mixtures in the present work are on the low side, but in any case it is obvious that in oxygen a very weak mixture indeed will ignite. The temperature developed by the combustion of such a mixture must be very low indeed, which would seem to suggest that fuels have not necessarily a high ignition temperature in weak mixtures.

Turning to the upper limits, the combustion here is obviously largely governed by the oxygen available. It might be expected, therefore, that the ratio of the vapour present to the oxygen available would be a constant. Some calculations carried out in this manner, however, show that this does not appear to be the case.

(*c*) Coming next to the ignition temperature factor, White has raised a very thorny point. The observed values for the ignition temperature of various bodies according to the experimental work of Dixon and of Moore are quite low, say from 200–600° C. It it were only necessary that an explosive mixture should, by its combustion, reach temperatures of this order a very much lower limit would be expected.

The question is raised by White of the influence of the time factor in ignition temperature measurements, and evidence is brought forward that ignition temperatures are dependent very largely on the time factor.

The ignition temperature of a gas at the lower limit may be high because of the paucity of infra-red radiation, and from the weak, non-luminous flame which is propagated. In experimental apparatus, such as that of Moore, the vapours are exposed to a very dense infra-red radiation, so that the ignition may be a cumulative effect, rather than an instantaneous value. This is borne out indeed by the "wait period" observed by Moore, amounting in some cases to more than 20 seconds. It is unfortunate that this time factor comes in, because it renders more difficult than ever the obtaining of any theoretical basis for limits.

(*d*) Very little work appears to have been done on the effect of pressure on the limits. With methane increase of pressure has

been found by Mason and Wheeler to raise both the lower and upper limits. In the case of each body examined in the present work the lower limit falls with increasing pressure and *vice versa*.

The following figures have been calculated for toluene, heptane and alcohol, assuming Dalton's Law to hold. The effect of the air pressure on the vapour pressure of the liquids will be negligible in this connection :—

Total Pressure. Atmospheres.	Lower Limit. Toluene.	Heptane.	Alcohol.
1	1·62	1·41	4·06
2	1·40	1·26	3·53
4	1·28	1·02	3·45
6	1·14	0·88	3·40

We have examined the flash-point figures obtained under pressure in connection with the vapour tension curves of the corresponding liquids, in so far as these are available. No very marked connection has been found as yet, but the following values for R have been calculated, and may be of interest in this connection :—

TABLE XVII.

Pressure =	1 atmo.	2 atmos.	3 atmos.	4 atmos.	5 atmos.	6 atmos.
Benzene (solid)	·746	·721	·706	—	—	—
„ (liquid)	—	—	·706	·700	·695	·689
Cyclo-hexane—						
Solid	·738	·708	·692	—	—	—
Liquid	—	—	—	·682	·676	·670
Heptane	·734	·709	·692	·680	·670	·662
Methyl Alcohol	·840	·822	·812	·804	·794	·788
Ethyl „	·818	·801	·796	·793	·790	·791
Propyl „	·817	·797	·788	·778	·772	·768
Amyl „	·776	·762	·756	no data		—

In expressing the experimental results by a formula of the type :—

$$f = n \log P - K$$

the constancy of the slope of the curves for hydrocarbons indicates that for these bodies "n" in the above formula is also constant. We also know that for hydrocarbons

$$f + 273 = \cdot 736B$$

where B is the boiling point in degrees absolute.

Combining these two formulæ we get

$$f_r = n \log P + \cdot 736B - \text{constant}.$$

Taking the values for toluene as being the most completely investigated, this formula becomes

$$f_r = 36 \cdot 9 \log P + \cdot 736B - 378 \cdot 6$$

and this should be applicable to any hydrocarbon whatsoever.

The following values have been calculated for various hydrocarbons under a total pressure of 6 atmospheres :—

TABLE XVIII.

F.	Flash-Point °C. of Hydrocarbons at 6 atmos. Calculated.	Observed.
Benzene	16·2 ..	20
Toluene	38·7 ..	37
m-Xylene	59·6 ..	59
Cyclo-hexane	16·9 ..	14
Methyl Cyclo-hexane	28·7 ..	28½
Turpentine	70 ..	66
Heptane	29·5 ..	22½

The agreement, except in the case of heptane, appears to be fairly satisfactory, but even closer results can be obtained if, instead of ·736 B, the experimentally-determined flash-point at one atmosphere is used in the calculation.

(*e*) The literature on the influence of temperature on lower limits is scanty, the only experimental work appearing to be that of Mason and Wheeler on methane, and that of White on ammonia, as already mentioned.

J. Newton Friend, referring to this subject, says :—"Rise of temperature tends to reduce the lower limit as theoretical considerations would lead us to expect. This is evident from the data given below, which refer to methane in air" :—

TABLE XIX.

Temp °C.	20	175	237	312	555	690
Lower Limit, CH_4 % Vol.	5·80	5·25	4·75	4·30	3·40	3·00

The last temperature given is not far short of the ignition temperature recently found by Mason and Wheeler (1) for methane-air, as determined by rushing the mixture into a heated quartz tube. The ignition temperature for a 3 per cent. mixture was found to be 700° C. ± 1°.

The mixture having the minimum ignition point contained about 6 per cent. of methane, and when this amount was diminished the ignition temperature rose It is possible that if the methane proportion were reduced to a very small figure a very much higher ignition temperature would be found, though it is hardly likely that this would be of such a high order as 1000° C. It would be, of course, extremely difficult to submit this matter to an experimental test, since surface combustion comes into play to a preponderating extent at such temperatures.

[1] J.C.S. 1922, 121, 2081

(*f*) The influence of the walls of the enclosure is very marked in determining lower limits for tubes of less than 5 cms. diameter. In the case of our flash-point apparatus the diameter of the bell is only some 2 cms., but on the other hand the flame has only to travel a cm. or so as against 1 metre to several metres in the case of the tube determinations. It is observed with tube work that with mixtures supposed to be just under the lower limit concentrations, the flame will travel part of the way along the tube and then become extinguished. This is, in part at any rate, due to the cooling of the flame by the cold walls of the tube.

In the flash-point apparatus it is only the start-off of the flame propagation which matters. It is probable that as the flame in the bell approaches the sides the strength of the mixture is increased by increased evaporation of the liquid being tested by the heat of the flame. This should tend to make the cooling effect of the bell have no further influence on the lower limit determined by means of the instrument.

Even in the method of determining lower limits by the tube method great differences arise from variations in the diameter of the tube, the length of the tube, and the method of firing. In consequence, even greater difference will arise when determining lower limits by deduction from flash-points determined in a more or less confined space. It is possible, where the vapour tension figures are available, to calculate flash-points from lower limit values, and *vice versa*. Taking the values given by White for the lower limits of various substances, the following flash-points have been calculated :—

TABLE XX.

Substance.	Calc. Flash-Point.	Observed Flash-Point.
Benzene	—15·5° ..	—12°
Toluene	5·0° ..	9°
Methyl Alcohol	11·0° ..	11°
Ethyl Alcohol	12·6° ..	14°

It will be noticed that the flash-points calculated in this manner are lower than those actually determined, and this is, as may be expected, owing to the influence of the small diameter of the flash-point instrument. In general, the effect of these various conditions on the determination of flash-points tends to make them so erratic that a flash-point can hardly be considered as an accurate constant.

In some recent work by R. Wright (1) the depression of the flash-point of alcohol by various solutes has been used to estimate the molecular weight of these solutes. The apparatus employed, it is claimed, gives flash-points accurate to 0·1°C., but the values are only relative, and are not absolute, the instrument giving a

figure for alcohol 3–4° above that obtained with ordinary instruments.

The authors desire to express their thanks to Mr. B. G. Banks and Mr. E. E. Connolly for carrying out much of the experimental work of these investigations.

This work may be regarded as a further portion of the extended investigation which is being carried out on the physical properties of pure and mixed fuels at the joint request of the Distillers' Company, Ltd., and the Fuel Research Board of the Department of Scientific and Industrial Research. We wish to take this opportunity of recognising the financial assistance rendered by them towards the expenses of this research.

DISCUSSION.

The President expressed the indebtedness of the Institution to Dr. Ormandy for the concise summary he had given of the work which had been done by Mr. Craven and himself. He was sure everyone would recognise that the authors had investigated certain subjects which called for investigation. They had broken ground which, to a large extent, was new and which must have a very important practical bearing on the behaviour of volatile fuels in internal-combustion engines. The remarkable effect of dissolved gases in solution and the extreme difficulty which the authors had experienced in getting rid of the gases had been previously noted, and he had encountered the same difficulty himself in determining vapour pressures. Perhaps the authors could give some inkling as to the nature of the dissolved gases. On the first page the authors had made a comparison between their results and those obtained by Ramsay and Young. The point occurred to him whether, in Ramsay and Young's work, any reference was made to the presence of dissolved gases. The next point to which he wished to refer was the temperature of ignition. He understood the authors to say that if an air-petrol mixture was passed into a cylinder, temperatures of over 700° C. were required to bring about ignition, but if the liquid was dropped into a heated cup, as in the Moore method, the ignition temperature was of the order of 260° C. Moore noted in some cases in his experiments what he termed a wait period of some seconds before the ignition took place. He was reminded by those observations of the work which was carried out by Engineer-Commander Hawkes, who was now a professor at Newcastle, at the Admiralty Engineering Laboratory, with a piece of apparatus which was made at his (the President's) suggestion, to endeavour to find the ignition temperature of oils under the

conditions of use in a Diesel engine cylinder. If the work of Hawkes was referred, to a very parallel instance would be found of the remarkable delay period that was obtained before combustion took place. It looked as if there was some initiation period, some phase of self-heating which, once it was started, would accelerate up to the point of ignition. There was another series of experiments which occurred to his mind, which he thought also had some bearing on the subject. Dixon made a number of most valuable determinations of the ignition points of gases by a flow method, by which the gas escaped from a tube and air or oxygen escaped from another concentric tube into a space which was gradually raised in temperature until ignition took place. Those figures were regarded quite rightly as very valuable ones, in fact almost as standard figures. But people were rather startled some three or four years afterwards, when David published some results of work which he had done on a soap bubble method of ignition. David blew up a bubble with his mixture of combustible gas, for instance, hydrogen and air, and brought it over a heated point, so that he obtained ignition and he measured the temperature very accurately by means of a thermo-junction, obtaining figures, two or three hundred degrees in some cases, above the figures which Dixon had obtained. It seemed to him (the President) that probably the big difference in the two sets of results were due to the same thing, namely, the initiation period before true combustion was set up.

He would not discuss the paper further, but ask Col. Tizard, with whose work in connexion with the problems of the behaviour of volatile fuels many members were familiar, to open the discussion.

Col. H. T. Tizard, after thanking the Institution for the invitation that had been extended to him to attend the meeting, said he desired to say, in reply to the last remark that Dr. Ormandy had made when giving his summary of the paper, that the Department of Scientific and Industrial Research was glad to render help on the recommendation of the Fuel Research Board to the investigation carried out by the authors because it attacked an important problem in a new and original manner. In doing so, he need hardly say that the Fuel Research Board did not demand immediate "practical" results.

With regard to the question of vapour pressure, it seemed to him very remarkable that the authors obtained such accurate results with the apparatus used. He should have thought himself that the difficulties were so great that it was almost hopeless to get accurate results of vapour pressure, even with a pure liquid, by means of methods which depended upon the removal of minute traces of air and other gases, and upon accurate measurements of very small differences in level between two mercury columns.

Still, one must judge by results obtained; and these, viewed in comparison with other very careful work, seemed to bear out the contention that quite accurate measurements of vapour pressure could be obtained by their method, even when the pressure was very small. At the same time the method was clearly entirely useless for a mixed liquid such as "petrol"; and in that connexion he might be forgiven for referring to a paper by Mr. Marshall and himself in the Proceedings of the Institution, in which they described an apparatus for obtaining the vapour pressures of mixed liquids which he thought could be developed in order to obtain accurate vapour pressures, both of pure substances and of mixtures at quite low temperatures.

So far as he could see, the empirical relation,

$$\frac{\text{Flash point °K}}{\text{Boiling point °K}} = \text{constant (R)}$$

which, evidently, was an approximation only, meant that at the flash-point temperature the partial pressure of the hydrocarbon vapour was a definite proportion of the partial pressure which would be needed for complete combustion. This seemed to be borne out by the figures given in Table VI., etc. It would have been interesting if the authors had given in each case the percentage vapour by volume necessary for complete combustion. This was approximately 2 per cent. in the case of toluene, and slightly less in the case of heptane. In an internal-combustion engine it was impossible, in spite of the high temperature of compression, to explode a mixture containing less than about 80 per cent. of the fuel required for complete combustion. It appeared that under the conditions of experiment employed by the authors, distinctly weaker mixtures could be exploded. He thought that the influence of turbulence, and of "delay" before ignition took place was sufficient to account for this difference. Turbulence would almost certainly raise the flash-point temperature. "Delay" would hardly affect the authors' results; but in the case of an engine it was a factor of importance, since if the delay was long, in the case of weak mixtures, the piston would be travelling downwards, and expanding the gases before ignition could occur. The authors stated that they could observe no delay in their experiments; but there must have been a delay, and from somewhat similar experiments carried out by other investigators he should judge that it was of the order of 1-25th second. The President had referred to the difficulty of finding a complete explanation for the delay period. In this connexion he might refer to a recent paper by Mr. D. R. Pye and himself in the *Philosophical Magazine*, on experiments on the sudden compression of explosive gases In this paper Mr. Pye and he had shown that

the delay was controlled by three main factors; the initial temperature of compression, the rate of loss of heat from the reacting gases, and the temperature coefficient of the gaseous reaction. If these three factors were known, the delay could be accurately calculated. A complete theoretical explanation of the phenomena observed could be given for such a case, which is comparatively simple from a theoretical point of view. The explanation would apply also to Hawke's results. But though the conditions were more complicated when ignition was caused by a spark, he thought the same principles must apply. Whether ignition spread or not, must depend on the temperature in the spark zone, the rate of loss of heat from the layer of gas surrounding the burnt portion, and the rate of reaction in this layer. For example, the authors found that the flash point was lowered when nitrogen was replaced by oxygen. This would be expected on the above theory, for though the initial temperature after passage of the spark was not higher, the rate of reaction in the gas round the spark zone would be higher, owing to the greater concentration of oxygen. When the authors replaced nitrogen by an equivalent volume of carbon dioxide, they found in some cases that the flash point was lowered. At first sight this may see surprising, for the maximum flame temperature must be lower; but it must also be remembered that carbon dioxide has not only a lower conductivity for heat than nitrogen and oxygen, but also that it absorbs quite strongly in the infra red, where nitrogen and oxygen show only very weak absorption. Hence the loss of heat, both by conduction and radiation, from the hot zone, must be smaller when carbon dioxide replaces nitrogen; and this effect may well counterbalance the effect of a lower initial temperature. The authors' interesting observations on the effect of carbon dioxide appear to have a close bearing on Ricardo's experiments on stopping "detonation" by diluting the inlet gases of an internal-combustion engine with exhaust or other inert gases. The delay observed when ignition temperatures were measured by Moore's method could be explained on similar grounds; in his view ignition by this method was preceded by a slow "catalytic" reaction on the solid surfaces. This would probably account for the low temperatures of ignition observed.

With regard to the effect of pressure on the flash point, and the constancy of the slope of the curves given in Figs. 5 and 6, it appeared to him possible that this was connected with the slope of the vapour pressure curve, and therefore with the latent heat of evaporation. He noticed that the substances which gave the same Trouton constant had parallel flash-point curves, and the authors had shown that the flash-point temperature was approximately proportional to the boiling point, and therefore to the molecular latent heat.

Perhaps an explanation of the authors' empirical equation for the effect of pressure could be found on these lines.

Mr. Watson said he felt highly honoured at being asked to attend the meeting, and he assured the members that he had been very greatly interested in what he had heard. The company to which he belonged (the L.G.O.C.) were certainly "very large petroleum consumers," and they therefore took a very keen interest in the theoretical side of the business, because they realised that the theoretical consideration of fuels had a very great influence on the practical side. The country was dependent upon such bodies as the Institution of Petroleum Technologists to give the lead in regard to future developments in fuel and every other aspect of their business than was the case in America. The L.G.O.C. went into such matters rather more fully than most other companies, chiefly for the reason that it used such a vast amount of fuel, and that the undertaking was probably the largest of the kind in the world. He did not propose to criticise the paper in any way, but only desired to remark that his Company realised very keenly the practical value of the theoretical study of the subject which the authors and the other members of the Institution were so thoroughly carrying out.

Major Cooper Key said that as an official who had been somewhat closely associated with the flash-point measurements, he desired to express his special thanks to the authors for showing what interesting features were attached to this somewhat elusive determination; but so far as the scientific aspect of the work was concerned, he was afraid he was hardly qualified to say anything. There was one point he might mention. He had heard that one reason for obtaining prompt explosions in the cylinder of a car was the extreme turbulence of the mixture, and he thought perhaps that might overcome the delayed explosion to which the authors had referred.

Mr. E. A. Evans said that if he remembered correctly when Dr. Ormandy read his last paper, before the Institution, dealing with the same subject, he asked him whether he had tried to remove the gases from the liquid by the usual method of passing a current of inert gas through it, and he believed he remembered Dr. Ormandy saying, in reply, that he had not actually done so, but he proposed to do so in the near future. The information was not given in the paper. Perhaps Dr. Ormandy was holding it back until a subsequent date.

Dr. Ormandy stated that the work had been done and the results had been published in the Journal in a paper by Messrs. Banks and Craven.

Mr. E. C. Craven said he had been extremely interested in the remarks made by Colonel Tizard regarding vapour pressure apparatus. Mr. Ormandy and he tried many forms, but if Colonel Tizard knew of a better apparatus the authors would be very glad to hear of it. The cathetometer with which the authors were supplied by the Department of Scientific and Industrial Research was found to be an extremely awkward instrument in its original form. Better results were obtained by replacing the telescope by a low power microscope, and obtaining readings in that way. If any of the members had experience of the use of cathetometers he would be pleased to have any information on the subject. He had been congratulating himself on Col. Tizard's remarks concerning the correlation between flash points under pressure and the form of the vapour tension curve at the temperature of the flash point. That had already occurred to him, and he had made several attempts to correlate the two curves on the basis of the Clausius-Clapeyron equation, but the degree of correlation had been very small, possibly because his mathematical ability was also small. Before leaving the subject of vapour pressures, Professor Brame had mentioned the fact that the results given in the paper agreed with those of Ramsay and Young, and that those investigators did not find it necessary to use elaborate precautions to remove gas. He would point out that the method used by Ramsay and Young was a dynamic method, *i.e.*, they determined the boiling point on cotton-wool *in vacuo*, so that the gases were brought off at the same time, and therefore could not affect the results to the same extent as when a static method was used. He thought the discrepancy which the authors found between the calorific value law, which had been pointed out by White and others, and their own results, arose from the fact that in tube experiments a very large vessel was being used, while in the case of the authors' experiments only a very small vessel was being used. He desired to say, in conclusion, that the whole feeling which had been produced in his mind by the work undertaken by Dr. Ormandy and himself was one of very great disappointment. They started off with very great hopes that the flash-point work they had undertaken would lead to results of scientific value; but his present feeling was that flash points were such unreliable things that their investigation did not seem to get them much further in the solution of the limit problem. The authors would, therefore, welcome any suggestions regarding the work they had undertaken, in order to obtain extensions of their results.

Mr. Gordon Pitt said that although the results at present, from a purely scientific point of view, were not as interesting as Mr. Craven had hoped, it needed very little imagination to see the

extended scope for blending, and the use of different types of fuel which would probably be found available for ordinary commercial, every-day work when the investigation was concluded. He thought that quite apart from its direct scientific value *per se*, the work that had been done by the authors would, when it was completed, prove of very great commercial value also.

Dr. W. R. Ormandy, in reply, said that the President had raised a question as to the nature of the dissolved gases. The effect that the dissolved gases produced was great; but their quantity was small. He thought, had Prof. Ramsay been alive, the apparatus which he employed in his study of the rare gases would have been admirably suited for a research of that nature. Even if he (Dr. Ormandy) had felt justified he did not think the Scientific and Industrial Research Board would consider he was justified in asking for that type of plant to make a research into the nature of gases, in view of the small quantities in which they were present. Something, however, had been done. In the research published by Messrs. Craven and Banks, on the dissolved gases contained in kerosene, it was at least proved, he thought, that they must have a molecular weight which was somewhere between ethylene and pentane. In other words, by drawing a measured volume of air through kerosene, noting the loss in weight and then adding the corresponding amount of pentane, that amount of pentane did not send the flash points down as much as it had been raised by the loss in weight. But, on the other hand, by putting in that weight of ethylene the flash point was lowered more than it should have been by the addition of the corresponding amount. All the authors could say was that the work showed that it was probably an unsaturated compound, and that it had a molecular weight somewhere of the order between ethylene and pentane. It was highly probable in the case of alcohol that it was acetaldehyde or a body of that class, but he could not say that the authors had tackled the problem. It would require a great deal of apparatus and the expenditure of a lot of time. Reference had been made by the President to the work done by David with regard to a soap bubble method of ignition, and also to Dixon's work. As an illustration of how difficult the problems were, he desired to point out that David in his work obtained a different flash point under varying conditions. He made a soap bubble run against a platinum wire, and it made a serious difference whether the platinum wire touched the bubble at the bottom, at the side or at the top, and whether the platinum was clean when it touched the bubble, or after the first or second or third time. When it touched the soap bubble once its surface was affected. The results depended on the nature of the surface, the temperature and the position, and the method could be ruled out

as a scientific method of determining any particular physical property. Dixon's work with a tube method, although very accurate, suffered from the same difficulty that was experienced in our hot gas experiments, connected with the surface on which the combustion took place. It was very difficult to eliminate the ever-present effect of surface. He had seen the results of work which had been carried out in the research laboratory of Krupps in Germany, further refinements having been employed, but, generally speaking, the results of Dixon had been substantiated. He was acquainted with Hawke's work, and that subject had also been dealt with by Col. Tizard. As Col. Tizard said, the apparatus which the authors employed in connexion with vapour pressures was only suitable for and was only used for pure liquids. Col. Tizard had stated that delay must have been present in the ignition carried out in the instrument referred to. He thought possibly it might be, but the time during which the heat was emitted was practically instantaneous, because a single spark of electricity was used. What lag there might be between the passing of the spark and the visible explosion it was difficult to say, and certainly it would be very difficult to measure. It might be done photographically, but it was a point the authors had not investigated. He had been very greatly interested in Col. Tizard's explanation of the possible reason for the peculiar behaviour of carbon dioxide—nitrogen relatively above and below a critical mixture percentage. He agreed with Col. Tizard that Dixon's results were not comparable. They merely showed that under certain conditions nitrogen and oxygen, at any rate, behaved simply by virtue of the percentage present, and had no specific action. Col. Tizard also referred to the Moore apparatus, and gave as a possible explanation that catalytic action was taking place on those large surfaces. If that was in any degree an explanation, the extraordinary thing was that it made no appreciable difference whether a platinum, porcelain, quartz, silver or copper surface was used, or anything else that had been tried. The results were not affected to any appreciable extent, and that, to his mind, made the proposal that catalysis was to some degree an explanation a very difficult one to adopt. He thought that possibly some further light might be thrown on the question if Moore's type of experiment could be carried out in various mixed gases under various pressures. That was a very desirable thing, because it had a great bearing on the Deisel engine practice. The authors had been fortunate in getting Messrs. Ricardo to make an instrument for them, which they had had in hand for some time. Mr. Watson spoke primarily of the interest which the L.G.O.C. took in the bearing of science on industry. He was glad to find that an engineer who was responsible for the

experimental work of the L.G.O.C. and its enormous undertakings was present at the meeting to inform the Institution that, at any rate, there was one big industrial corporation in this country which realised that even very dry scientific facts and curves relating to vapour pressures had a bearing on industry, and were worth the money they cost. If Major Cooper Key, who dealt with the question of turbulence, visited the meetings of the Institution of Automobile Engineers, as he occasionally visited the meetings of the Institution of Petroleum Technologists, he would find that the question of turbulence had probably been the most discussed question in the motor industry for a considerable period of time. It did not, however, enter into the experiments that the authors were carrying out, to any considerable degree, except in so far as they were dealing with the influence of temperature where the gases were in motion ; and in that connexion it had already been pointed out that the higher speeds tended to show a lower limit as being capable of ignition.

Mr. Arnold Philip, who was also called upon to speak, said that the paper dealt with the question of Flash Point from, what was to him, a novel standpoint, and he did not feel capable of making any useful criticism. The investigations, however, were of the greatest interest and he wished to congratulate the authors upon the lucid manner in which they had described the results of their work.

On the motion of the President a hearty vote of thanks was accorded to the authors for their excellent paper, and the meeting terminated.

International Liquid Fuel Congress.

Held at Paris, October 10th to 14th, 1922.

PREFACE.

THE Third International Conference of Chemistry, held at Lyons, from June 27th to July 1st, 1922, was a meeting of the International Union of Pure and Applied Chemistry. The decisions arrived at at that Congress were embodied under sixteen headings, to be found in the " Compte Rendu Analytique de la Troisième Conférence Internationale de la Chimie," published by the Union Internationale de la Chimie, 49, Rue des Mathurins, Paris. Paragraph 12 reads as follows :—

" En ce qui concerne la création des laboratoires nationaux et internationaux des combustibles et des produits céramiques, les Sous-Commissions des combustibles solides, liquides et gazeux réunies proposent tout d'abord à l'Union d'inviter chaque Etat adhérent à établir dans son pays, par les soins d'un délégué ou d'une Commission :

1°. La nomenclature des divers combustibles, les définitions légales et industrielles sous lesquelles ils sont désignés, avec l'indication précise de leurs propriétés physiques, chimiques, physico-chimiques, organoleptiques;

2°. La liste des, méthodes et appareils de recherches d'analyse, de vérification, de prévision, officiels ou d'un emploi très général, pour permettre aux chimistes, aux ingénieurs et aux industriels de s'entendre, soit en vue d'une unification éventuelle, soit pour atteindre un but plus immédiat : savoir exactement quels sont les écarts ou les différences entre ces méthodes, afin d'éviter toute discussion inutile.

Elles émettent le voeu que les laboratoires nationaux dé jà existants ou à créer dans chaque État adhérent, en dehors des recherches spéciales ou des vérifications pour lesquelles ils ont étéscréés ou seront créés, puissent tenir le plus grand compte, avec l'appui des Gouvernements, des directives de la Commission internationale des combustibles."

The meeting in Paris of the International Liquid Fuel Congress appointed a Committee to draw up a schedule emphasising the points upon which informatioü was required from all countries, in order that at the next International Conference, to be held at

Cambridge in June, 1923, there should be material available which, in the hands of a competent Committee, might lead to some degree of unification in nomenclature and testing methods. Even where the desired degree of unification of nomenclature could not be arrived at, there would, at least, be material put forward officially by the representatives in each country, which could be published under the ægis of the International Conference, and thus brought to the notice of all those interested in the subject in various countries. Where similar methods could not be employed, the next best thing is to know clearly the nature of the methods used in other countries. The Institution of Petroleum Technologists have formed a very active Standardisation Committee, and it is clearly the duty of that committee to take up the matter for Great Britain, and, as far as possible, for the British Empire. It was indeed recognised at the Conference in Paris that, to a very great extent, the question of nomenclature and analytical methods would have to be guided by American and English practice, as in these countries these questions had already received greater attention than elsewhere.

W. R. O.

DELEGATES REPORT.

Having been requested by the Council to represent the Institution at this Congress, we left for Paris on October 8th. On the evening of October 9th the foreign delegates and a great number of the members of the Congress attended a reception held at the Palais d'Orsay, under the auspices of the Organisation Committee.

The following morning the official opening of the Congress took place.

The President of the Congress was Prof. Paul Sabatier (Membre de l'Institut), Dean of the Faculty of Science of the University of Toulouse, the well-known authority on catalysis. The Congress having been organised by the Société de Chimie Industrielle, the President, Mr. Paul Kestner, took a very active part on the official and social side.

At the opening meeting the outstanding event was the paper read by Mr. Daniel Berthelot (Membre de l'Institut), entitled "l'Etude Scientifique des Carburants." In a beautifully clear and eloquent speech Mr. Berthelot set forth the present official attitude towards the liquid fuel problem and the question of the use of industrial alcohol for this purpose.

In the afternoon the question of Nomenclature and Specifications of Liquid Fuels was discussed, and it was decided to refer this important matter to a Committee that would meet at the Ministry of Commerce on the following morning.

On October 11th this Committee met at 10.30 a.m., and after an opening speech by Mr. Daniel Berthelot (President) the attitude of the French Committee was fully exposed by Prof. Bordas and Mr. Nicolardot. At the suggestion of the Italian delegates, and more particularly at that of Mr. Amoretti, the whole subject was referred to a small sub-committee, on which the following delegates were requested to sit :—

Argentine	Mr. Saubidet.
Belgium	Mr. Debacqz.
Chili	Mr. Bertrand.
Spain	Mr. Mora.
United States ..	Messrs. Seidell, Cobb and Houston.
France	Prof. Bordas.
Great Britain ..	Dr. W. R. Ormandy and Mr. G. W. E. Gibson.
Italy	Mr. Amoretti.
Luxemburg	Mr. Kemp.
Poland	Mr. Horajn.
Rumania	Mr. G. Gane.
Switzerland	Dr. Schläpfer.

Secretary : Mr. Nicolardot.

In the afternoon this sub-committee met, and in the unavoidable absence of Mr. Daniel Berthelot the presidency fell to Mr. Amoretti. After a prolonged deliberation, it was decided that each country represented should hand in the following questionnaire, setting forth the actual commercial and scientific practice relating to the respective liquid fuels—petroleum products, shale, benzole and alcohol in the several countries.

Dénominations commerciales.

Caractères organalytiques (couleurs, fluorescence, odeur, etc.).

Caractéres Physiques—

Densité	Température ? rapportée à l'eau	appareil
	Coefficient de dilation choisi	utilisé
Point d'inflammabilité		id.
Point d'ignition		id.
Limites de distillation ou fractionnement		id.
Fluidité ou viscosité		id.
Point de congélation		id.
Pouvoir Calorifique		id.
Soufre (total et combiné)		id.

ORIGINE :

USAGES :

REMARQUES ET OBSERVATIONS :

Pour certains produits seront mentionnés, en outre, le rendement en gaz, la teneur en phénols et celle des produits non saturés avec l'indication exacte des méthodes et des appareils utilisés pour les déterminer.

Les renseignements fournis pour les alcools, considérés seulement comme combustibles (carburants) seront identiques à ceux établis par la Commission Française, en se rapprochant le plus possible du formulaire précité.

At the suggestion of Prof. Bordas it was further decided that each country should hand in a separate statement respecting its wishes with regard to the question of a uniform nomenclature.

At 5 p.m. on October 10th the Congress was received at the Hotel de Ville by the Municipality of Paris, and on the afternoon of October 11th the foreign delegates and numerous members of the Congress were entertained at luncheon by the Société de Chimie Industrielle.

On October 11th, 12th and 13th a vast number of papers were read, and these will be published shortly by the Société de Chimie Industrielle.

We think that a mere recital of the titles would be tiresome, but papers of especial interest were, perhaps, those presented by Paul de Chambrier, C. Schlumberger, G. Gane, Dr. Waterman and J. N. J. Perquin, and by Profs. Gault and Maihle in the Petroleum Section; those by Rear-Admiral Philip Dumas and E. H. Cunningham Craig and Ch. Berthelot in the Shale Section; those by Ch. Berthelot, Mariller and Hellemans in the Lignite and Turf Section; by Connerade and Ch. Berthelot in the Tar and Benzole Section; by Vernet and Meunier in the Alcohol Section; and by Prof. Mailhe and Luc in the Vegetable Oil Section.

We are of opinion that, on a future occasion, a more drastic selection will have to be made, and the number of papers limited to about five or six per day, and that those based on original research work only should be accepted, for under the system adopted an adequate discussion was impossible.

At the closing session a very remarkable paper, on "la Préparation du Pétrole à l'aide d'Huiles Vegetales et Animales," was read by Prof. Mailhe, of the University of Toulouse, and was received with great enthusiasm by a numerous audience.

The Congress terminated by an official banquet, presided over by Mr. Le Troquer, Minister of Public Works. The exhibition held in connection with the Congress was one of the best of this kind we have seen. Several interesting oil engines and numerous liquid fuel burners were shown at work, and the several oil companies operating in France were well represented. Judging from the crowds that were present when we happened to visit the exhibition, this bold venture must have been a commercial success.

In conclusion, we wish to add that the tact, the courtesy and the energy shown by Mr. Jean Gérard, the hard-working secretary of the Congress (the secretary also of the Société de Chimie Industrielle), was beyond all praise.

DR. W. R. ORMANDY.
G. W. E. GIBSON.

THE EXCURSION TO STRASBOURG.

As it was quite impossible, owing to numerous important engagements in London, for Dr. Ormandy to take part in either of the excursions arranged by the Congress, the writer decided to join Group II., that was leaving for Strasbourg on October 15th. Immediately after arriving at Strasbourg we were received by the Faculty of Science at the University, and after a short and eloquent speech of welcome by Prof. Muller, the Dean of the Faculty of Science, we had the great pleasure of hearing Prof. Henry Gault, director of the Petroleum Section of this University, explain the aims and aspirations of this new and interesting venture. Subsequently we visited the several laboratories, and also the immense—and much too costly—aula. In the evening a short reception took place, under the auspices of the "Amis de l'Université," when we had the pleasure of hearing a very excellent speech of Mr. Paul Kestner.

At 9 a.m. on October 16th we proceeded by road to visit the "Péchelbronn" Mines, where we were received with the well-known hospitality of the Board, and shown everything of interest. At luncheon speeches were made by Mr. Paul de Chambrier and Mr. Paul Kestner, dealing principally with the highly interesting history of "Péchelbronn," and Mr. L. Pineau, the Chief of the French Petroleum Dept., in a graceful and witty speech, thanked the numerous foreign delegates for the interest shown in the Congress, and more especially in the "Péchelbronn" Mines.

We then visited the well-known foundry of the de Diétrich Company, where we were also received with the proverbial Alsatian hospitality. That evening the foreign delegates and the members of the Congress attending this excursion were entertained at a banquet organised by the Société Industrielle du Rhin. This was attended by Mr. Alapetite, Commissaire Général of the Government in Alsace and Lorraine, Mr. Aliez, Préfet du Bas-Rhin and General d'Armau de Pouydraguin, Military Governor of Strasbourg.

After speeches by the President of the Société Industrielle du Rhin and Mr. Paul Kestner, the writer had the honour of thanking

the Congress for the hospitality and kindness shown to your Institution.

On October 17th at 8.01 a.m. we left Strasbourg for Saarbrücken, where we were met on arrival by Mr. Granière, assistant director-general of the Saar Coal Mines. Before luncheon we had a short but admirable lecture by Mr. Granière on the present position of the Saar Coal Mines, with especial reference to the highly interesting and valuable experiments that are being made on Low Temperature Carbonisation. Immediately after luncheon we visited the important and highly efficient coke-oven plant of these mines, and on our return we visited the celebrated engineering works of Messrs. Erhard and Sehmer.

At 8.56 p.m. we left for Paris, after spending a somewhat tiring but highly instructive and interesting three days in one of the most picturesque and hospitable corners of France. This excursion was made very instructive and pleasant, due to the presence of a great number of the foreign delegates, including amongst others: Prince Ginori Conti (Italy), Mr. G. Gane (Rumania), Prof. Kogerman (Esthonia), Dr. Wibaut (Netherlands), Dr. Schläpfer (Switzerland), Prof. Hauser (Spain), Mr. Hallback (Sweden), and Mr. Kavan (Czecho-Slovakia), in addition to many of the more important French members such as: Prof. Bordas, Messrs. L. Pineau, Paul Kestner, Nicolardot, C. Schlumberger (director of Péchelbronn), F. Gaudouin (dir. Cie. Occidentale des Produits du Pétrole), and Jean Gérard (secretary of the Congress).

Prof. Sabatier was unavoidably prevented from taking part in this excursion.

G. W. E. Gibson.

Comments on Mr. Miller's Paper, the Galician-Canadian System of Pole Tool Drilling.

By J. C. TEMPLETON.

CONCERNING the number of cases of collapsed columns quoted by the author, it is to be regretted that neither the paper nor the discussion arrived at any conclusion on the subject. The following is the table of the Boryslaw Casing, as given by the author with two columns added, one showing the calculated collapsing pressure of each string of casing, and the other showing the factor of safety based on the calculated collapsing pressure and the depth to which each column is usually taken :—

BORYSLAW—TUSTANOWICE CASING.

Nominal size. In.	Outside Dia. in m/m.	Inside Dia. in m/m.	Thickness of walls in m/m.	Calculated collapsing pressure. Equivalent water column. Metres.	Depth to which usually taken in metres.	Factor of safety.
14	355	337	9	568	120	4·73
12	305	289	8	620	400	1·55
10	267	253	7	621	600	—0·96
9	231	217	7	827	1000	—0·827
7	195	181	7	1150	1350	—0·85
6	163	148	7·5	1735	1650	1·05
5	132	118	7	2140	1800	1·18

Collapsing pressure calculated according to Stewart's formula for lap-welded Bessemer steel tubes :*

$$P = 1000 \left(1 - \sqrt{1 - 1600 \frac{t^2}{d^2}}\right) \ldots\ldots \text{A}$$

$$P = 86{,}670 \frac{t}{d} - 1386 \ldots\ldots\ldots\ldots \text{B}$$

P = collapsing pressure in tubes per square inch ; d = outside diameter of pipe in inches ; t = thickness of wall in inches.

Formula A is for values $t \div d$ less than 0.023, while Formula B is for values greater than these.

The formula from which the column of collapsing pressures is calculated is that of Stewart, and which is based on the results of a most complete research undertaken by him at the works of the National Tube Co. The formula is accepted by many American authorities, and has the blessing of the U.S.A. Bureau of Mines. Hazeltine's paper giving full details of this research is well worth the study by all who are interested in Petroleum Fields Engineering.

* See Hazeltine, R. S., Collapsing Pressure of Steel Tubes, West Engineering, Vol. I., July, 1912.

The above table shows clearly, in my opinion, why so many instances of collapsed casing have occurred in Galicia, particularly in the cases of the 10 in., 9 in. and 7 in. sizes, the factor of safety in each of those sizes being considerably under 1.

It may be argued that the strength of the casing may vary according to the type of casing employed, *e.g.*, lap-welded or solid drawn pipes, or according to the strength of the material, *e.g.*, 35–40 kgrms. steel or 55–65 kgrms. steel. To some extent this is so, but from tests personally observed this difference does not exceed 25 per cent. in excess of the calculated collapsing pressure by above formula when 55–65 kgrms. solid drawn pipe was tested.

Even with this additional strength, it is, I consider, seeking casing troubles to work with factors of safety such as is apparently the practice in Galicia.

When one considers the number and extent of unknown underground factors, any of which, if present, is more detrimental to casing than the bare column of water behind the shoe, *e.g.*, shifting sands, swelling clays, loose formations with boulders, trapped gas pressure, etc., etc., it seems to me obvious that such factors should be provided for on every field by maintaining a sufficiently large factor of safety, based on the calculated collapsing pressure of each size of casing.

In the discussion, suggestions were made *re* the draining of the water from behind the set column, but who can say that further leakage will not occur; such drainage could only be attempted in columns which are not shutting off water. Further, such solutions make no provision for the factors which cannot be drained, such as pressure from swelling clays, shifting or loose formations, etc. To me there appears to be only one way to deal with this question, and that is to have the casing sufficiently strong to meet in full factors calculable plus *at least* 100 per cent. to meet the unexpected and unknown. In advocating a factor of safety of at least 2, based on a column of mud with sp. gr. of 1.3 behind the shoe and to the top, I feel sure, from my own experience, it will amply repay oil companies to take no chances in this respect.

At this point I would remark that there are few, if any, above ground engineering structures where the factor of safety is allowed to fall as low as 2. Therefore, why take risks with a structure which is out of sight, and where many of the forces cannot be calculated?

In conclusion, I would further suggest that all casing specifications, instead of providing for an inside test pressure, should contain provision for an outside test pressure. By covering the weaker, which, in this case, is the outside pressure, the inside test is automatically covered. Further, by far the greatest number of casing failures are from outside pressure.